Final report

Nexus project – exploring profitable, sustainable livestock businesses in an increasingly variable climate
Milestone 8, Final Report

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Abstract

The Nexus project explored options for livestock businesses to adapt to the changing climate and reduce greenhouse gas emissions using four case studies in central Queensland, northern New South Wales (NSW), northern Victoria and East Gippsland. The project analysed future farm options (‘Base’, ‘Adapt’, ‘Towards carbon neutral’ and ‘Diversify and Grow’) using biophysical modelling, farm economics, and social research approaches together with regional reference groups who ensured that the work was regionally relevant. The research showed that warmer and drier climates will reduce pasture growth and farm profitability if businesses are operated in the same way, but the impact varied across regions. The Adapt option highlighted the opportunities and benefits for adaptation by implementing changes to feedbase and animal performance, with increased profit observed in all case studies and was consider achievable by the reference groups. Growing the farm business was predicted to be highly profitable but with increased financial risk. The Towards carbon neutral pathway achieved greenhouse gas emissions reduction mainly due to carbon sequestration in trees, highlighting a lack of practical mitigation options for pasture-based production systems. It was considered mostly unworkable by the reference groups. The project also evaluated the role of new technologies and made recommendations for future research, development and extension in the context of adapting to the changing climate and achieving emissions reduction on farms.

Executive summary

Background

The climate across eastern Australia has changed over recent decades, with increasing temperatures and changing rainfall patterns across the region. Livestock production is also under pressure to meet industry and consumer challenges and demands for increased sustainability, for example, by reducing greenhouse gas (GHG) emissions. The Nexus project investigated livestock farm production systems of the future by exploring pathways for adaptation to a changing climate and reducing GHG emissions. A key outcome from the research was to identify future research, development, and extension priorities for adaptation to the future climate and lower GHG emissions systems.

Objectives

The aim of the project was to investigate future farm options that would adapt production systems to future conditions, including the changed climate and lower GHG emissions, using four case study farms in Central Queensland, northern NSW, northern Victoria and East Gippsland. Modelling approaches were used to estimate the impact of future climate scenarios on production, GHG emissions and profit. Social research investigated the adaptive capacity of farmers to make changes to their farm businesses. The objectives have been achieved.

Methodology

The project used transdisciplinary research approaches, incorporating biophysical modelling, farm economics, social research and regional producers/consultants, to explore pathways for adaptation to 2030 and 2050 future climate scenarios and reduce GHG emissions on four case study farms. Regional reference groups established for each case study had a key role in guiding the research and providing feedback on the results. Four future options were modelled: (1) Base farm, continue to operate the business as it is currently, (2) Adapt, using current technology improve pasture and animal production to suit the changing climate, (3) Towards Carbon Neutral, where the aim was to reduce net GHG emissions towards zero, and (4) Diversify and Grow, which expanded the livestock business sometimes into new regions. Transformational technologies, including new pastures, increased animal efficiency and a slow release methane inhibitor suitable for use in pasture-based systems, were also investigated.

Results/key findings

For all of the case studies, if the farm operated the same way in the warmer climates expected in 2030 and 2050 then profit was predicted to decline, particularly at the Victorian sites where rainfall reductions were more pronounced. This highlights the importance of adapting livestock production systems to the changing climate over the coming decades. The Adapt option, which consisted of improving the feedbase with a focus on summer-active pastures and improving reproduction rates of livestock, was more profitable than the base farm indicating that farm systems changes are available to reduce the impact of climate change. This pathway was considered achievable by the reference groups. The Diversify and Grow option was usually the most profitable but also had the highest year-to-year variation and financial risk. It was considered an attractive pathway by the reference groups, but external factors can determine its feasibility and it will not be an option for the whole industry. The emissions reduction in towards carbon neutral option relied heavily on tree planting highlighting the lack of current options for pasture-based systems. Reducing emissions will impose additional costs on the farm businesses. It was considered an inevitable change by the reference groups but mostly unworkable with current technologies.

Social research highlighted a general tendency for Nexus reference groups to perceive that they had more capacity to implement the 'Adapt' and 'Diversity & grow' pathways, and less capacity to implement the 'Towards carbon neutral' pathway. Of the five capitals assessed (humans, natural, social, financial and physical), there was a general perception across the reference groups of having less capacity for adaptation regardless of the pathway when it comes to drawing on social, financial and physical capitals (resources). Support for adaptation to regional climate change may therefore need to focus on investing in building and strengthening a range of social resources (such as policy settings, agricultural farm services and producer learning networks), financial resources (such as lending conditions of financial institutions, farm profitability and financial risk analyses) and physical resources (such as farm water storage, regional water infrastructure and ICT infrastructure) to enhance the adaptive capacity of Nexus reference group producers.

New pastures, with higher energy content and increased summer-activity, showed promise to increase profitability of livestock businesses, particularly in the 'hot and dry' climate scenarios. Increased animal efficiency (reduced mature size of breeder with same turnoff) reduced the emissions intensity of livestock production but led to increased total farm emissions if additional livestock were used to graze the excess pasture that was created from the more-efficient livestock. A slow-release methane inhibitor that reduce enteric methane emissions by 80% has potential to reduce net farm greenhouse gas emission to approximately one third of the base farm. Further research into pasture, animal efficiency and methane inhibitors will be essential for achieving the dual aims of adapting to the changing climate and reducing farm greenhouse gas emissions.

Benefits to industry

This is the first project to identify pathways for the livestock industry to both adapt to the changing climate and reduce GHG emissions. The pathways mainly use existing technologies and highlight practical options to achieve adaptation and GHG reductions, and highlight that leading farmers are making changes to adapt and reduce GHG emissions intensity of livestock production. It has also highlighted the important role that new technologies will play in achieving the dual aims of adaptation and mitigation.

The project has also established a series case study farms that can be used in future research and development projects to model the impacts of changes at a whole farm system level, and piloted a social research methodology for producers and advisers to self-assess their current adaptive capacity for implementing options for adaptation and mitigation and where future extension and advisory support could be targeted.

Future research and recommendations

The Nexus project highlighted the important need for livestock production systems to adapt to the changing climate in order to maintain profitability. The project identified research, development and extension priorities for the industry to adapt to future conditions. While some of the research priorities were regionally specific, common elements included pasture improvement, increased animal production efficiency and use of tree planting on farm to reduce net GHG emissions. A strong focus on improved extension and advisory services to support adaptation and greenhouse gas mitigation was also identified.

Feedbase related research recommendations focussed on options to maximise forage production during the reliable part of the growth season (eg. winter and early spring in southern Australia) as well as options to extend the growing season, but noting that suitable species suited to climate and soil types are not available in all regions. Pasture-based options to reduce methane emissions, utilising species with appropriate plant secondary compounds, was also a high priority across the regions. Regional, science-based testing of factors known to limited pasture productivity (including climate) was recommended. Animal management research and development priorities identified include improving animal feed efficiency to provide both adaptation and mitigation benefits, and methods to deliver feed additive that reduce enteric methane production in pasture-based systems. Business structure and risk management options to reduce the risk of extreme climate events/natural disasters (bushfire, multi-year drought, floods). These individual extreme events were not fully explored in the Nexus project but merit further investigation, may link to other recommendations such as spatial diversification. Recommendations for future extension and advisory services were focused on investing in region-based testing of adaptation and mitigation options in both commercial and research contexts over the mid-term (3-5) years as well as developing the skills and knowledge of service providers to advise on carbon neutral agriculture and identify risk management strategies when considering, investing and implementing new approaches and practices for adaptation more generally.

Table of contents

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1. Background

The climate across eastern Australia has changed over recent decades, with increasing temperatures across the region and also to meet industry and consumer challenges and demands for increased sustainability, for example, by reducing greenhouse gas (GHG) emissions. The Nexus project is investigating livestock farm production systems of the future by exploring pathways for adaptation to a changing climate and reducing GHG emissions.

In north-eastern Australia, extended, severe drought has occurred in many regions, while in south-eastern Australia, later autumn breaks and increased variation in the spring season (including a marked increase in the frequency of failed springs, Perera *et al.* 2019) has put pressure on current production systems by reducing pasture availability and feed reserves. Livestock businesses need to adapt to the changes that have already occurred and prepare for the anticipated climate changes over the next decade including further increases to temperature and a greater frequency of extreme climate events such as heat waves and extreme rainfall (CSIRO and Bureau of Meteorology 2022). Previous studies of climate change adaptation (for example the Southern Livestock Adaptation 2030 project) focussed on climate scenarios where the changes were considered to occur incrementally (eg. Cullen et al. 2009). Changes in the frequency and size of rainfall events (ie. rain occurring in fewer but larger events) has a greater impact on farm businesses in addition to incremental climate changes (Harrison et al. 2016). While providing some insights for adaptation, such as use of deeper rooted and summer active species (Ghahramani and Moore 2015) and legume introduction in northern Australia (Ash et al. 2015; Crimp et al. 2016), these projects tend to underestimate the climate changes that have occurred and therefore the scale of the adaptation challenge. There is also new evidence emerging about the frequency and severity of climate extremes expected that must be considered in future adaptation studies (CSIRO and Bureau of Meteorology 2022).

There is an increasing need to reduce GHG emissions from livestock production for red meat production to demonstrate its environmental sustainability (Mayberry *et al.* 2019). There are many opportunities to reduce GHG emissions from livestock production systems, including animal management, breeding and feeding strategies (see for examples Eckard *et al.* 2010; Cottle *et al.* 2011). There is also an emerging body of evidence that examines the role of carbon sequestration in trees and/or soil to mitigate farm GHG emissions (e.g., Doran-Browne *et al.* 2016; Sinnett *et al.* 2016; Doran-Browne *et al.* 2018). Farm case studies provide insights into the potential for GHG mitigation through animal management and breeding (e.g., Cullen *et al.* 2016) or use of feed additives (Alvarez Hess *et al.* 2019), sequestration in soil and trees (Doran-Browne *et al.* 2016, 2018), but should be supported by robust economic analysis, including co-benefits, to provide a complete analysis for producers to make informed decisions (Sinnett *et al.* 2016). There is a lack of case studies exploring the opportunities for GHG mitigation and sequestration in farm systems combined with economic analysis across various livestock production systems and climatic zones.

The 'NEXUS' series of projects is a multi-party program of research that explores the nexus between profitability, productivity, greenhouse gas mitigation, carbon sequestration and consumer perceptions of livestock businesses in an increasingly variable climate. An integrated assessment of seven farm case studies in regions from the northern Queensland to the Midlands of Tasmania (Figure 1) is underway to identify systems adaptations that are profitable, environmentally sustainable and targeted towards future market opportunities. This report focusses on four case study farms in Central Queensland, upper Hunter region of northern New South Wales, northern Victoria and East Gippsland Victoria.

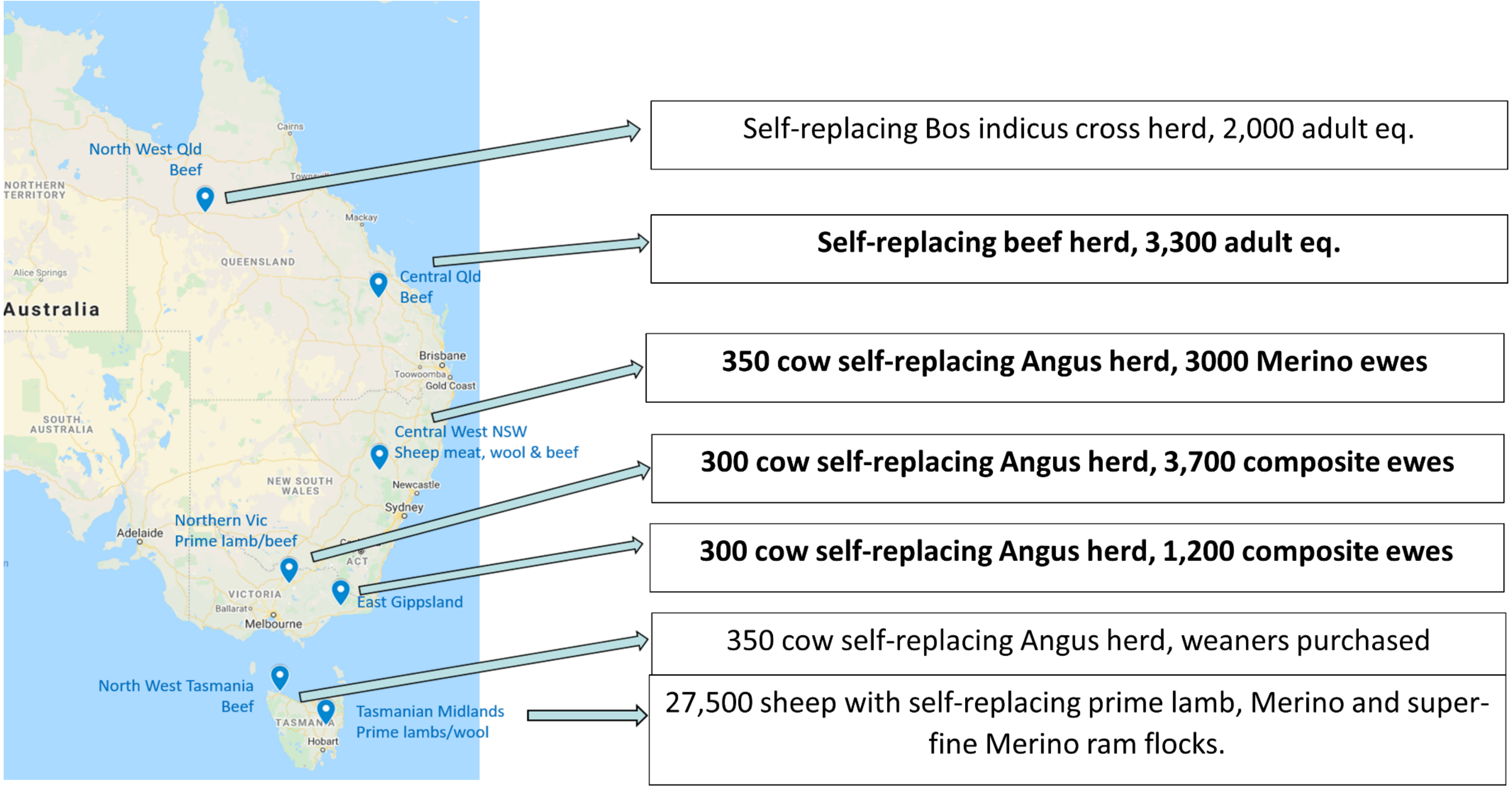


Figure 1. Nexus project case study locations and brief description of livestock systems. The Central Queensland, northern NSW, northern Victoria and East Gippsland case studies included in this report are highlighted in bold.

2. Objectives

By the 1st of May 2023 the participant will, for each of the identified regions, have:

- Objective one - Modelled the impact of climate change scenarios against two-time horizons – indicatively 2030 and 2050 - on sheep and beef production systems using both scaled and variable approaches. (NB. USQ case study does not include the 2050 climate scenarios).

  Achieved.

- Objective two – Identified 10 prospective high-priority research themes each for the sheep, beef and feedbase areas that mitigate the long-term impact of a changing climate. These themes will then be refined through engagement with regional reference groups to identify the most prospective areas for further investigation. (NB. The Central Queensland site run by the University of Southern Queensland will have 4-6 high-priority themes covering beef and feedbase).

  Achieved.

- Objective three - Engaged a minimum of 10 producers in strategic activities – per region - to explore the profitability and resilience of their production systems against future climate change scenarios. (NB. USQ to use existing reference group members).

  Achieved.

- Objective four - Calculated greenhouse gas emissions on each individual case study farm, investigated prospective abatement or mitigation methods and modelled the impacts of these strategies on total emissions. (NB. USQ case study does not include the investigation of abatement options).

  Achieved.

- Objective five – Implemented a minimum of one 'Involve and Partner' activity/ies to pilot initial adaptation (objective 2) or greenhouse gas mitigation (objective 4) or emergent Livestock Productivity Partnership project (s) recommendations. This will include initiation of an on-farm practice change activity based on emergent recommendations*. (NB. USQ case study does not include objective 5).

  Achieved.

- Objective six – Identify the human and social capacities and capabilities required to manage the modelled scenarios at farm and industry scale. Propose strategies to assess industry readiness to respond and engage producers and farm advisors in building capacity for adaptation and transformation. (NB. USQ case study does not include objective 6).

  Achieved.

*Initiation of an 'involve and partner' activity is a required deliverable as outlined in the milestones. However, the structure and resourcing of this activity will be formulated at the appropriate project milestone, as the 'involve and partner' activities are not resourced in the budget associated with the current schedule. The clear expectation is that a separate co-funded activity will be established, linked to this agreement, through a separate project schedule.

3. Methodology

3.1 Overview and role of the Regional Reference Groups

The Nexus project used a transdisciplinary research approach to explore the production, economic and social dimensions of climate change adaptation and GHG emission mitigation in livestock production systems. The research involved farm systems modelling, farm economics, social research and farmers/service providers. The project established regional reference groups in three regions as part of the University of Melbourne project (northern NSW, northern Victoria and East Gippsland, Victoria) and one in the University of Southern Queensland project (central Queensland). Case study farms were identified with input from the reference groups.

Each regional reference group consisted of 5-6 farmers and consultants in the region. They met 5-7 times throughout the project. The regional reference groups guided the project in each region, including identifying a case study farm, developing an initial list of adaptation options, defining future farm options, and providing feedback on the project results. Due to COVID-19 travel restrictions, the reference group meetings the majority were held via videoconference however, there were at least two face-to-face meetings in each region. Details of project reference group meetings are provided in section 4.7.

3.2 Case Study Farms

3.2.1 East Gippsland

The case study farm business has two properties (Clifton Creek and Tambo Crossing). The property was purchased 10 years ago. The farm has been impacted by drought, and fire in 2007 and 2019/20. The property has an area of 664 hectares with the feedbase containing a mixture of 20-30% annual forage cropping, 60% area sown temperate pastures (phalaris, cocksfoot, prairie grass, sub clover, lucerne) and 10% steep hill unusable area. The farm has invested in feeding and water infrastructure to be better prepared for future climate variability. A 'steady state' livestock enterprise was defined with the case study farmer, and is briefly described as:

- Sheep: self-replacing composite ewe flock. 800 mature ewes and 400 ewe lambs joined per year. Lambing in July, with 150% lamb making. All wether lambs (820hd) sold in January at 44kg liveweight and 420 ewes lambs sold in May weighing 53kg liveweight.
- Cattle: Self-replacing herd. 250 mixed-age cows joined. 95% calving for mature cows and 85% for first calf heifers. Approximately 50 steers and 50 heifers were sold in May (280 kg liveweight). Further, 70 steers were sold in September (340 kg liveweight).
- Traded livestock:
    - Lambs: 2000 purchased in January (32 kg) and sold in April (52 kg).
    - Cows: 40 cows with calf purchased in October and sold in May/June; calves sold at 10 months at 280kg liveweight.

For the modelling, pasture types were classified as improved (phalaris, annual clovers, lucerne) or unimproved (native grass-based), and there was assumed to be 81 ha of improved pasture at Clifton Creek and at Tambo Crossing, there was 100 ha improved pasture, 40 ha forage crop and 379 ha unimproved pasture in the base farm.

3.2.2 Northern Victoria

The northern Victoria region case study farm has two properties:

- 1330 ha near Violet Town (-36.6235, 145.7181) with pastures predominantly of annual grasses, subterranean clover with some phalaris; and
- 288 ha near Strathbogie (-36.8472, 145.7308) with pastures predominantly phalaris and subterranean clover.

The property at Violet Town is the original farm in the business, Strathbogie was purchased over the last 12 years to provide complementary pasture production patterns and spread the climate risk faced by the business.

The climate varies considerably across the two properties, with Violet Town having the lowest rainfall and highest temperatures and Strathbogie, at 500 m elevation, having the highest rainfall and coolest temperatures. The high rainfall and low winter temperatures at Strathbogie provide a reliable farm water supply compared to Violet Town. The average and range of annual rainfall (1990-2019) is 600 (239-1021 mm) and 907 (410-1425mm) at Violet Town and Strathbogie, respectively. Variability in annual rainfall, as measured by the coefficient of variation (CV), is lower at Strathbogie than at Violet Town (CV of 26 and 31%, respectively). The high rainfall and low winter temperatures at Strathbogie provide a reliable farm water supply compared to Violet Town.

The pasture growth patterns differ substantially between the properties, reflecting the climatic conditions and pasture types. Violet Town has a relatively short growing season of approximately 6 months compared to 8-9 months on the other properties. The different climates and seasonal production patterns provide an opportunity to manage risk in the business.

The livestock are a mix of sheep and beef.

- Sheep: self-replacing composite ewe flock.
    - 3145 mature ewes (July lambing - 140% - at Violet Town) and 617 ewe lambs (September lambing – 110% - at Strathbogie) joined per year.
    - All wether and surplus ewe lambs sold in December (Violet Town) and January (Strathbogie).
- Cattle: Self-replacing herd.
    - 300 mixed age cows joined (95% calving)
    - Steers and surplus heifers at 14-15 months age (480 kg liveweight).

There are 120 ha of mature trees and plantations on the properties, consisting of patches of 4-15 ha that have not been cleared) and four more recent plantations of 800-900 m long by 30-40 m wide, with plans to establish another one. These plantations serve as shelter belts and habitat connections between creeks and roads.

3.2.3 Northern NSW

The case study farm is in the northern Hunter region of New South Wales between Coolah and Cassilis (31 deg 52, 149 deg 51). The property has been in the family for three generations with a member of the next generation now entering the business. The soil type on the property is a predominantly black, heavy clay basalt soils. The region an annual average rainfall of 626 mm (1990-2019) with 60% of the rainfall occurring in the warmer months from October to March. Annual rainfall is highly variable ranging from 322-1052 mm, with rainfall in the three years from 2017-2019 being significantly below average with 450 mm, 383 mm and 361 mm, much of which occurred in a few large rainfall events. Flexibility in the livestock enterprise to respond to variable seasons is a key aspect of management.

The property has an effective area of 1821 hectares. About 320 ha is arable land containing a mixture of sown pastures (including lucerne/phalaris mix and digit subtropical species) and forage crops (grazing oats or barley), with native pastures making up most of the area (1500 ha). The main native grasses in the mix is Stipa, but it also includes a mix with Danthonia and Microlaena giving the potential for year-round growth. Sown pastures failed to persist through the recent drought. Only a small amount of superphosphate is applied to pastures (8 tonnes per year, mainly to fodder crops).

The livestock on the property is a mix of sheep and beef. The main enterprise is a self-replacing Merino ewe flock (ewe liveweight 60-70 kg). Typical breeding ewe numbers are 3000-3500, but numbers were reduced to 1600 during the 2017-2019 drought. Lambing commences on 1 August for 5 weeks. The lambing percentage at weaning is 140%. One-third of the wether lambs are sold at 10-12 months (50 kg liveweight, 21-22 kg carcass weight), while the remaining two-thirds are sold as trade lambs at 35 kg liveweight. Ewe lambs are kept until their second shearing at 18 months of age, with numbers retained or sold depending on the number required to maintain or increase the size of the breeding flock. The annual cull rate is about 20% of the breeding flock.

The beef breeding cows activity (British breeds or European cross) would typically be about 350 cows, though the numbers are highly variable depending on seasonal conditions. During the 2017-2019 drought, all the beef animals were sold, with re-stocking commencing in 2020. Due to variations in numbers breeding cows will be purchased or sold as required. Calving is usually in August, although this can vary depending on the cows purchased, with 95% calving rate. Weaners are sold at 6-8 months of age at 250-300 kg liveweight.

Flexibility to adapt to seasonal conditions is a key management strategy (e.g., planned exit points for selling a stock). Stock numbers are manipulated to match feed supply and demand, with cattle numbers adjusted before sheep.

A ‘steady state’ livestock enterprise was defined with the case study farmer, and is briefly described as:

- Sheep: self-replacing Merino ewe flock with some cross-breds. 3500 mature ewes (August lambing, 126% lamb weaning overall). All wether lambs sold at 35kg or 50kg. Merino ewe lambs kept to 18 months age are classed and joined (replacement ewes) or sold.
- Cattle: Self-replacing herd.350 mixed age cows joined. Calving in August. 90% weaning. Surplus heifers and steers sold at ≈9 months age.

Tree planting on the property has been limited to 10 hectares because of low tree survival due to drought. The terrain is too difficult to manually water trees and the farmer considers the labour cost too high and success rate too low to invest time, effort and capital in planting trees.

3.2.4 Central Queensland

The property is located south-east of Moura (Latitude/longitude: -24.59/150.09). It has a total area of 8800 ha, average annual precipitation of 630 mm (148 years), long-term annual mean temperature of

21.4°C and average woody vegetation cover of 1.3%. Land types include Brigalow with blackbutt (Dawson gum) (65%), Poplar box with shrubby understorey (27%), Blue gum/river red gum flats (3%), Brigalow softwood scrub (3%), Mountain coolibah woodlands (2%), Softwood scrub (<1%) (Figure 1). Soil types include Brigalow belah, red loams, and black clay, with mostly improved pastures. Water use is currently all surface water from dams.

The sustainable herd size is 3300 head (close to 3300 AE) of cows, calves, steers, bullocks and bulls. The controlled mating program joins females in December, January, and February, calving in late spring/early summer. The average weaning rate of mature cows is 90% (we could not replicate this level in the modelling). Animal numbers are adjusted due to seasonal conditions, but the objective is to keep cows until 18 years and steers until 600kg (usually 3.5 years). The average birthweight is 38 kg, with an average growth rate of 0.5 kg/d.

3.3 Future Climate Scenarios

Climate scenarios for 2030 and 2050 were created to represent the projected changes in each region with the daily climate data generated using the method of Harrison et al. (2016) to capture more of the changes in extreme climate events. Six different climate scenarios (each consisting of 20-year intervals) were investigated at the NSW and Victorian sites. The climate scenarios are summarised as:

- Baseline climate– 1986-2005 climate data from Bureau of Meteorology (BoM). This is period is used as the climate to be consistent with the methods for the climate projections.
- Recent climate – 2000-2019 climate data from BoM.
- 2030 Median climate – applied ‘mid-range’ projections for temperature and rainfall change at 2030.
- 2030 Hot & Dry climate – applied ‘high range’ (90th percentile) projections for increasing temperature and declining rainfall at 2030.
- 2050 Median climate – applied ‘mid-range’ projections for temperature and rainfall change at 2050.
- 2050 Hot & Dry climate – applied ‘high range (90th percentile) projections for increasing temperature and declining rainfall at 2050.

Climate change projections for rainfall and temperature changes were sourced from the Victorian Climate Change Projections 2019 (https://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/victorian-climate-projections-2019/) And the Adapt NSW project (https://www.climatechange.environment.nsw.gov.au/home). All the climate scenarios used assumed a high greenhouse gas emission pathway (Representative concentration pathway 8.5). Atmospheric carbon dioxide concentrations were assumed to be 350 ppm for Baseline, 380 ppm for Recent, 450 ppm for 2030 scenarios and 530 ppm for 2050 scenarios.

The modelling for the central Queensland site is only for historical and 2030 scenarios, in accordance with the milestone requirement for that case study. The future climate for Australian cluster East Coast 2030 was derived from the AR5 projections change scenario RCP 8.5 using the future projections for monthly changes in temperature and rainfall (https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-futures-tool/projections/) and entering these values into the change calculator prepared and described by Harrison et al. (2016) to perturb the historical daily climate data (1975-2013) with the change factors and generate a climate file for 2030.

3.4 Biophysical modelling approach

Biophysical modelling was conducted using the most suitable tool in each region. The SGS Pasture model predicted monthly pasture growth and quality (MJ ME/kg DM) in northern Victoria, Gippsland and northern NSW. Feed demand from livestock was estimated monthly, and then seasonal feed supply and demand were assessed in a bioeconomic model. The GRASP and CLEM tools were used in central Queensland. GRASP was used for the simulation of pasture growth, total standing dry matter (TSDM), utilisation, animal intake and other variables, then the growth variable was then used in CLEM for animal and other herd output.

Modelling results were presented to the reference groups for feedback and to inform the discussions about climate change impact and adaptation options.

The SB-GAF calculator (SB-GAF version 1; Dunn *et al.* 2020) was used to estimate greenhouse emissions from the farms. The tool uses the Australian government approaches to estimate Scope 1 (on-farm methane, nitrous oxide and carbon dioxide emissions from diesel consumption), 2 (electricity usage) and 3 (purchased farm inputs) emissions from farms. Total farm emissions are expressed as tonnes of carbon dioxide equivalents (t CO_2e). The Global Warming Potential (GWP) of methane and nitrous oxide were 28 and 265, respectively. The tool is available at: http://www.greenhouse.unimelb.edu.au/Tools.htm.

Carbon sequestration from tree plantings or managed regrowth on the case study farms was estimated using LOOC-C (https://looc-c.farm/). This considered the area, age and species of trees planted.

The emissions intensity (EI) was estimated for beef, sheep meat and wool on the case study farms, using SB-GAF version 5. The protein mass allocation method (Wiedemann *et al.* 2015) was used to partition emission from sheep to meat or wool. The protein content of wool was 100%, while that for meat (sheep and beef) was set at 18% (Wiedemann *et al.* 2015b). Total GHG emissions for meat and wool was calculated using the ratio of protein content in each product relative to total farm protein production.

3.5 Future Farm options

Four themes for future farm options were defined in the project and then the specific characteristics of the options were defined in consultation with the regional reference groups. The four themes were:

- Base case – continue to operate the farm as it has been.
- Adapt – continual improvement of production systems to adapt to warmer and drier future climates. This included pasture improvement, improved animal production and changes to management.
- Towards carbon neutral – reduce GHG emissions to zero using sequestration and mitigation options. This included the use of feed additive where practical and carbon sequestration in trees.
- Diversify and grow – develop a larger farm system with diversification of pasture type or location. This included purchasing additional land and expanding the livestock business, either in the same location or in a spatially diverse region.

The specific details of the options for each region differed according to the case study. The options are described in the Results section of this report.

In addition, four transformational Research and development options were explored to examine their potential effects on GHG emissions and farm profitability. These options represented future technologies that are not currently available and were defined from the 'transformational webinars' held in the project and the scientific literature:

- Feedbase: high ME pastures (+ 1 MJ ME/kg DM) at East Gippsland and Northern NSW sites (eg. Ludemann *et al.* 2015) and a summer-active legume (based on lucerne) in northern Victoria.
- Animal efficiency: reduced mature breeder size (by 5-10%) with same level of production. Smaller mature size will consume less pasture and produce less methane, providing both adaptation and GHG mitigation benefits.
- Methane inhibitor: a slow-release rumen bolus suitable for grazing livestock that could achieve 80% methane reduction from weaned livestock (both sheep and cattle). The assumption of 80% reduction was based on recent studies with additives in feedlots (Kelly and Kebreab 2023), and that this result could eventually be achieved with a bolus in grazing livestock. The cost of such technology is not known but was assumed to be an annual cost of $30/hd for cattle and $15/hd sheep.
- Feedbase, Animal efficiency and Methane inhibitor options combined.

In Central Queensland the modelled adaptation options were based on improved feedbase, management and genetics:

- Improved pasture - increasing grass basal area (GBA) by 2% e.g., from the current 3% to 5%.
- Improved reproduction - the relevant coefficients for the equation relating animal liveweight to conception rates are set to achieve an increase in the average weaning rates by 5%.
- Improved growth rates - the growth conversion efficiency coefficients adjusted to improve a liveweight growth improvement of 10%.
- Improved rumen function - facilitating better digestion of low-quality pasture: monthly decline in digestibility of 8% used instead of 10% decay rate, a lower limit on digestibility is raised by 3%, e.g., from 43% to 46% digestibility.

3.6 Economic analysis

To carry out this research, the approach developed in the Dairy Directions project (Malcolm *et al* 2012) and used in the Lamb Directions program (Tocker *et al* 2016) was applied (Malcolm *et al* 2012). The Dairy Directions/Lamb Directions approach is characterized by using real farm case studies the whole farm approach (Malcolm *et al* 2005) and an advisory reference group to identify the technical feasible changes to current farm plans and to analyse the economic merit, risk and return of alternative futures for businesses facing changing conditions. The key to this research method is grounding the analysis in real farms and defining rigorously the 'types' of farms that are to be analysed as the case study farms.

The farm case study analyses encompass economics, finance, and risk (defined as volatility of profits and cash flows).

This research was built on the following base situation:

Currently the case study farmer is using the resources which they control in the best way they can, to achieve as many of their goals as they can, given the climatic conditions and economic conditions under which they have to operate.

The question for the research was: under different climatic conditions, how might the same farm with the same and/or additional resources be run, to meet as many of the farmers goals as can be achieved? The farmer goals are defined as building wealth subject to acceptable risk.

To answer this question, a stochastic whole farm discounted net cash flow budget was developed. For each case study, the analysis was based on buying the farm and running the farm as defined for each alternate future described earlier, under six different climate scenarios (defined earlier), for 20 years, then selling the farm at the end of the 20 years. This budget was used to model the possible economic and financial outcomes from running the farm in eight different ways under six different climate scenarios with and without a price on greenhouse gas emissions.

The key components of this stochastic whole farm discounted net cash flow budget were: technical inputs (for example feed supply and demand); economic inputs; and risk.

The changes in climate were reflected through pasture growth. In the budget a probability distribution of pasture growth, derived from SGS modelling, was developed for each season, each year, for each climate scenario and each alternate future. In addition, an estimate of feed demand for each season and for each alternate future was developed. To estimate feed demand, a calendar of events that captured the timing of calving, lambing and animal growth rates was developed with each of the case study farmers and the RRG. This calendar of events was then used to estimate the megajoules of metabolizable energy for each animal on the farm throughout the year for each of the eight alternate futures (see the appendix for the detailed assumptions for each case study).

Dynamics too are important. Dynamic effects add complexity to this type of farm analysis and quickly the curse of dimensionality takes hold. Still the reality that as seasonal conditions and prices change within a product period or for a run of types of production conditions, farmers respond: they change their farm plan as seasons and prices dictate. Handling this complexity in this type of analytical work requires ingenuity and proxy methods. Some insights can be garnered from running discrete scenarios to see how the farm business performs if say several changes occurred and the farmer made these changes, for this period of time. Alternatively, the costs of responding to changed seasons or prices can be incorporated in a proxy way. Suppose the effects of a drought on returns and risk needs to be included. One method is to 'pretend' to run the farm to 'usual' capacity, maintaining stocking rate by 'buying in' feed to meet the feed shortage caused by the drought. In practice, the farmer may do many things in response to a shortage of feed, all of which will impose a cost on the business. By incurring additional costs to maintain the farm plan in the face of the changed circumstances of lower than usual rainfall, an effect of drought on profit is included, even if the actual dynamic responses of the farmer will be a mix of quite different steps.

In this research, this method of using proxies to value the effects of different climates was used. It was assumed the farmer would buy in feed (or sell surplus feed) rather than change the farm system. That is, it was assumed that for each alternate future the output for that defined future was 'fixed' such that feed demand remained the same and was met by either pasture growth or supplementary feed. This approach used supplementary feed as the balancing item as new feed surpluses or shortages arise. Shortages were met with extra supplementary feed purchases, and surpluses were valued at their minimum value (cost of conserved feed less cost of conserving the pasture).

The costs and benefits were determined by the case study farmer and the RRG. A probability distribution was fitted to CPI adjusted price data from Thomas Elder for the period 2011 to 2021. These prices are the medium-term perspective for most likely prices which are less than boom prices but includes a probability of high and low prices as have been seen over the past decade. Note: whilst it is conceivable that future distributions of commodity prices under changed climate may exhibit increased volatility, with broader distributions than the recent past, this possible effect has been excluded to not distract from or distort the economic results affected by changed climate, by also having an arbitrary assumption about greater price volatility under future changed climates.

In judging alternative changes for the farm system, the risk versus return characteristics of the development options were important. To capture the risk dimension, the whole farm development budgets included probabilistic estimates (using the program @RISK) for key risky variables, such as pasture consumed, prices for outputs from the farm system like (meat and wool) as well as other market outputs (for example carbon) and costs of inputs like purchased feed. Correlations between key risky variables were accounted for in the probability analysis.

The effect of a price on carbon were also considered through including a cost on greenhouse gas emissions. To include this cost, an estimate of Greenhouse Gas (GHG) emissions for each case study farm, for each climate scenario and for each alternate future was estimated and it was assumed the social cost of carbon would be between \$60/tCO2e and \$100/tCO2e. It was assumed the farm will pay 35% of this cost and the remainder will be borne by others in the value chain (see Mounter *et.al* 2019).

The core assumptions for each budget for each case study were:

- Assumed real risk-free opportunity cost of capital is 4 % p. a. (the risk of running the business were accounted for in the modelling)
- Assumed inflation averages at 3 % p.a over the 20 years
- Assumed the annual real capital gain on the land is approximately 2% p.a (although it could be as low as 1% and as much as 4%).

Each case study farm budget model, for each alternate future and climate scenario, was 'run' for 20 years, with each run of 20 years repeated thousands of times, selecting from probability distributions of pasture consumed and product prices and costs. This simulation resulted in a probability distribution of Net Present Values (NPV) of the annual net cash flows over a run of years, after allowing for the 7% p.a. nominal cost of the capital tied up in the farm could earn in its next best use. Net Present Value (NPV) is the extra wealth above what would be earned from the next best capital investment.

The overall criteria to judge each alternate future was the extent to which the possible future farm scenario helped the case study farmer achieve their goals, which comes down to how well the farm creates the wealth the farmer needs to give them choices to do the things they want to meet their goals. The 'best' future was the one that had the largest addition to wealth (NPV) that the farmer could afford within the funds allocated for the investment and for the level of risk they were prepared to accept. For the same risk, more NPV/Wealth was better than less. If the NPV was equal to zero, then that investment was likely to be as good as an alternate investment in the economy, earning a 7% p.a. nominal return. If the NPV was more than zero, then it was likely to earn more than 7% p.a. nominal return. If the NPV was less than zero, then it was unlikely that investment would earn 7% p.a. nominal return. The changes in farm plans that add most to farmers achieving their goals, become areas for extension and further research.

Finance matters too, so, as well as the economic analysis, financial analysis was conducted to assess the financial feasibility of the alternative farm plans. It was assumed that each case study farm business had 85% equity in the 'base' farm business, which decreased for each of the alternative farm futures (as they had higher capital requirements). It was assumed the terms of the loan were 15 year loan at 7% p.a. interest. The financial implications were assessed based on the likelihood of annual net cash flow being positive after debt servicing.

3.7 Social research

The participatory approach applied in the conduct of the farm system, and economic modelling is considered by the social research team to be an application of the 'adaptation pathways' approach (Craddock-Henry et al., 2021). This approach involves facilitating stakeholder engagement, strengthening local capacity in thinking and planning for adaptation, and exploring multiple possible futures, the adaptation pathways approach incorporates an exploration of both short-term actions and long-term strategies as a planning tool for conceptualising a sequence of actions over time (Lawrence and Haasnoot, 2017) whilst anticipating that plans are dynamic and may need to be adjusted and consideration of shifting actions in response to changing conditions (Craddock-Henry et al., 2021).

Through the participatory approach, the social research team used mixed methods in data collection, including focus groups (group activity and discussions) and survey-questionnaires to capture the views and capacities of the reference group members in relation to the Nexus adaptation pathways (table 1). The key strength of applying a mixed method approach is that the research benefits from being able to generate detailed and contextualised insights from the qualitative data and develop broad perspectives and generalizations from the quantitative data.

Table 1. Data collection methods used, and data set generated to answer social research questions

Social research questions	Data collection methods	Data set
1. What are the human and social capacities and capabilities required to put the adaptive pathways into practice at the farm and regional scale?	• (2021-2023) Reference Group focus groups	• Reference group meeting transcripts and meeting summaries
2. What are the key opportunities and challenges for implementing the adaptation pathways by the red meat industry?	• (November 2022- March 2023) Survey – adaptive capacity assessment questionnaire • (2021-2023) Reference Group focus groups	• Questionnaire responses (quantitative and qualitative data) • Reference group meeting transcripts and meeting summaries
3. What are the key elements of an enabling environment to support climate related adaptive and transformative decision making in red meat production?	• (2021-2023) Reference Group focus groups • (May 2022) Survey - Carbon Neutral Agriculture seminar feedback form	• Meeting notes/scribing on butchers' paper • Questionnaire responses (quantitative and qualitative data)

General characteristics of the Northern Victoria, East Gippsland and Northern NSW Nexus reference groups

The general characteristics of the Nexus reference groups were collected through the questionnaire. The characteristics include group composition and age, property size or number of clients serviced, commercial agricultural activities or advisory serviced provided, years of experience in livestock production or provision of advisory services, stage of livestock business and farm workforce.

Northern Victoria Nexus reference group

Group composition and age of producers

There were three producers and two advisers in this group involving 4 men and 1 woman. However only two out of three producers were able to complete the questionnaire. The two producers were aged over 55 (but younger than 75).

Property size and commercial agricultural activities

The two producers who provided general characteristics of their livestock business indicated that the property sizes were 1850ha and 2600ha respectively. The main focus of the livestock businesses was breeding beef cattle. However one livestock business also included prime lamb, and the other business included cattle finishing, merino wool and mutton production.

Experience in livestock production, stage of livestock business and farm workforce

The two producers have been involved in livestock production for over 30 years. Both livestock businesses were preparing for family farm succession, however one business was still in the establishment stage. In terms of farm workforce, one livestock business employed farm staff at 2 FTE, while the other producer employed farm staff at 3 FTE, supported by part-time family involvement as well as several contractors.

Adviser characteristics

The two advisers were over the age of 55 (but younger than 75 years of age). The number of clients serviced varied greatly from 20 for one adviser and 200 for the other adviser. The main services provided included pasture agronomy, grazing management, sheep and beef cattle management, farm business analysis and benchmarking. Both advisers had over 30 years of professional experience.

East Gippsland Nexus reference group

Group composition and age of producers

There were four producers and one adviser in this group involving 3 men and 2 women. This reference group had a slightly younger membership to the Northern Victoria reference group. There were two producers under the age of 45, and one producer under the age of 55. One producer was over 55.

Property size and commercial agricultural activities

The property sizes of the livestock business varied greatly – from 120 ha to 1400 ha. The main focus of the livestock businesses was breeding cattle. However this was managed alongside raising lambs, sheep and trading cattle. One producer was also involved in bobby calf buying.

Experience in livestock production, stage of livestock business and farm workforce

The level of experience in livestock production was significantly less than in Northern Victoria – with all four producers with less than 31 years of experience. Two producers had less than 10 years of experience. Three producers were in the expanding/growing stage of their livestock business, with one producer at the established stage. In terms of farm workforce, there were small farm teams involved. One producer employed farm staff at 1 FTE, another producer employed 0.7 FTE, with part-time family involvement and another producer had family members involved at 2 FTE with 1 FTE staff member. One producer was self-employed.

Adviser characteristics

The one adviser was aged of 55 (but younger than 75 years of age). The number of clients serviced was 100 producers. The main services provided included animal health, grazing management, reproductive management, nutrition and stocking rates. The adviser had under 21 years of professional experience.

Northern NSW Nexus reference group

Group composition and age of producers

There were three producers and two advisers in this group involving 4 men and 1 woman. One of the advisers identified themselves as a being a producer for the purposes of the questionnaire. Similar to the East Gippsland reference group, this reference group had a slightly younger membership to the Northern Victoria reference group. There were two producers under the age of 45 and two producers over the age of 55, but under 75 years of age.

Property size and commercial agricultural activities

The property sizes of the livestock business varied greatly – from 607 ha to 4169 ha. The main focus of the livestock businesses was: breeding beef cattle (vealings/yearlings/restocking weaners), merino stud and wool and lamb production. Other side enterprises included cattle trading, self-replacing merinos, dual purpose winter cropping and wheat.

Experience in livestock production, stage of livestock business and farm workforce

The level of experience in livestock production was evenly split between under 31 years of experience and over 31 years of experience, with one producer with over 40 years of experience. Two producers were at the stage of expanding and growing the business (with one of these farmers doing so as part of a family farm succession process). One producer had reached the established stage while the other producer was in the process of family farm succession. In terms of farm workforce, there were slightly larger farm teams involved compared to the Northern Victoria and East Gippsland. One producer involved family at 1 FTE, employed farm staff at 1 FTE with four contractors. One producer involved family at 2 FTE. One producer involved family at 1 FTE, employed farm staff at 1.5 FTE with contractors at 2.5 FTE. One producer involved family at 3 FTE, and employed farm staff at 2 FTE.

Adviser characteristics

The one adviser was aged 75 or older. The number of clients serviced could not be confirmed however they were involved in large group events including field days, meeting, farm visits and using media outlets. The main services provided included pastures, fodder crops and soil management. The adviser more than 40 years of professional experience.

Reference Group focus group activities

The reference group meetings were harnessed as efficient and effective events for conducting a series of focus group sessions for:

a) identifying the possible adaptation activities for their region
b) prioritizing the adaptation activities for modelling
c) rating the ease of adoption of priority activities
d) discussing possible implications from implementing an adaptation pathway
e) brainstorming RD&E ideas for recommendation

f) discussing the adaptive capacity assessment results
g) Gaining verbal feedback on Nexus project process

Survey – adaptive capacity assessment questionnaire

A survey-questionnaire was developed in collaboration with the University of Melbourne (UoM) social research team and the Nexus social researcher from the Tasmanian Institute of Agriculture (TIA). The purpose of the survey-questionnaire was to systematically learn how each reference group member assessed the Nexus adaptation pathways in terms of their own or their clients' capacity to implement each pathway based on their views. Therefore, the survey was not attempting to develop a definitive inventory of all the currently available resources for adaptation in the region. It was also used as a mechanism to get the reference groups to start thinking of potential R&D proposals to enhance climate change adaptation and what extension and advisory services may be needed.

The questionnaire was treated as an exercise in piloting a strategy for indicating producer readiness for climate change adaptation in the red meat industry. If the strategy was considered successful based on data generated and feedback from the reference groups, then there is the potential for MLA to conduct an adapted and improved version of the questionnaire with their own producer networks.

The questionnaire was developed using two key concepts from the academic literature:

1. **Adaptive capacity:** refers to the set of capitals (natural, physical, human, social, financial) that are available/accessible for use in adapting to change, such as climate extremes as it occurs and the capability to deploy these resources for an appropriate response (Leith & Haward, 2010; Nelson et al., 2007).

2. **Sustainable Livelihood Framework:** The sustainable livelihoods framework has traditionally been used to organize the factors that constrain or enhance livelihood opportunities by looking at the vulnerability context, the capitals available, and the factors influencing the availability and use of capitals to develop strategies for increasing well-being, higher income, improved food security and reduced vulnerability. It is usually done at the household level.

Table 2. Description of the five capitals used in the Sustainable Livelihood Framework.

Capital	Examples
Human	capacity to learn, human resource management, decision-making and prioritizing, skills and knowledge, motivation, attitudes towards risk and uncertainty, confidence, independence/self determination
Social	family unit, formal and informal social networks, access and contributions to information/services, engagement with policy and governance system, trust and reciprocity
Financial	Financial assets, access credit based on equity, land prices, freight costs, financial policy
Physical	general infrastructure (machinery, irrigation, fencing, technologies) and specific farm infrastructure for responding to climate change (feed pads, water troughs), road and rail networks, farm size, genetics, technology, water infrastructure
Natural	pasture/crop species and genetics, water resources, soil health, biodiversity, land capability, animal health, welfare and genetics, pests, weeds and diseases
Cultural (additional)	**i**nfluence of family norms, community values, food production ethics

This framework is also used for climate change adaptation research to assess the resilience and vulnerability of communities (including agricultural and natural resource management communities) to the impacts of climate-related changes. Previous assessments of adaptive capacity using the Sustainable Livelihood Framework have tended to use secondary statistical data (e.g., population demographics) as the indicators (Lockwood et al., 2015), referring to a general capacity to adapt to climate change (and other drivers of change) with an emphasis on the availability and access to financial capital. What doesn't appear to have been done extensively is for people to assess their own adaptive capacity based on their views of available/accessible capitals in relation to specific adaptation scenarios (pathways) that they have co-developed. Drawing on previous research, we noted the indicators that were considered important in determining people's capacity to adapt using a self-assessment approach. Please see table 2 for a list of adaptive capacity indicators used to guide the questionnaire design.

The first half of the questionnaire asked the reference group members to rate their or their client's adaptive capacity by agreeing, disagreeing or neither agreeing nor disagreeing with the statement (neutral position). We purposely skewed each statement towards the capital (or resources) being available/accessible. The assumption was that if a reference group member agreed/strongly agreed with a statement, then they were indicating that a particular capital (or resource) was available or being used, while if a reference group member disagreed/strongly disagreed with a statement, then they were indicating that a particular capital (or resource) was not available or not in use. Therefore, responses that scored 4&5 were considered as indicating more adaptive capacity than those responses that scored 1&2. The rating scale is a relative scale, not an absolute scale.

Table 3. Groupings of rated adaptive capacity statements to indicate 'less capacity', 'neutral' or 'more capacity'.

Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
1	2	3	4	5
Less capacity (orange)		**Neutral (grey)**	**More capacity (blue)**	

We provided a neither agree nor disagree option for rating the statements because we didn't want to force reference group members to an either agree or disagree position if they weren't sure how to assess the capital, if they didn't think it was a relevant indicator of adaptive capacity or if they didn't have a strong view either way or some other reason. At the risk of receiving lots of 'neutral responses', we assumed an agree or disagree response was given with some level of confidence in representing their views.

The questionnaire was administered as either an electronic Word document or a link to an online version using Qualtrics (UoM's online survey tool). Each reference group was provided with an introduction to the questionnaire (aims, key concepts, features, ethics). Then it was either completed during a regular reference group meeting during a lunch break or reference group members completed the survey at their own convenience. The questionnaire data was then collated and converted into graphs or summarised text and presented back to the reference groups in a face-to-face meeting. A summary of the social research, including the questionnaire responses, will be provided to each reference group upon the final report being approved by MLA.

The questionnaire was adapted to whether the reference group member was a producer or adviser. Both producers and advisers responded to the questionnaire. The response rate for a completed questionnaire was as follows:

- Northern Victoria: 4/5 members (one member was unavailable to do the survey)
- East Gippsland: 5/5 members
- Tasmania: 4/6 members
- Northern NSW: 5/5 members

The limitations of the questionnaire design are that it is only surveying a small sample of producers and advisers (n=18). Therefore, the questionnaire findings cannot be generalised to the region or red meat industry. The findings represent each reference group only however, the findings can be used for a cross-reference group comparison. Assessments of adaptive capacity will change over time as conditions change. Therefore, the questionnaire is only capturing views at one point in time. It is also possible that we would get different responses if we had a larger sample that included a greater diversity of producers and advisers in the region.

Rationale for change of data collection methods from producer semi-structured interviews to a questionnaire

Originally the social research methods included semi-structured interviews with reference group members (and possibly producers/advisers outside the reference groups). However, it was decided that a questionnaire would best use the time and resources available. Engagement with the reference group members was significantly disrupted due to Covid-19 and case study regions experiencing major flooding events. The social research was also delayed due to waiting for the appointment of the TIA social researchers to coordinate our adaptive capacity data collection for a cross-reference group analysis and to allow enough time for the full development of the adaptation pathways for the reference groups to evaluate with some integrity.

Survey (feedback form) – participant feedback of the 'Nexus Carbon Neutral Agriculture' seminar

The purpose of the survey was to capture how valuable the seminar was for participants in terms of acquiring new knowledge, filling any knowledge gaps and if what they had learnt would lead to any action being taken. All participating members were asked to self-assess their seminar experience by rating their knowledge about carbon neutral agriculture before/after the event, indicating their views about the seminar by rating a series of agree/disagree statements and responding to 3 open-ended questions using a text box.

A total of 25 out of 34 invitees participated in the survey, resulting in a total response rate of 73%. All seminar respondents from the Nexus East Gippsland Reference Group were included in the target audience, excluding the NEXUS project team members.

Human ethics

The reference group meeting focus groups and survey questionnaire were approved by the University of Melbourne's Human Ethics Advisory Committee (Ethics approval #2057428.1). All reference group members were given a Plain Language Statement and a Consent Form to gain informed consent to document the workshop as a data collection exercise. All reference group members received written summary notes of each reference group meeting and a verbal presentation of the key survey results. The plan is to provide all reference group members with a written summary of the social research findings (including a complete presentation of the survey results).

4. Results

4.1 East Gippsland

4.1.1 Impacts of Future climates on pasture production

Future climate projections for East Gippsland indicate increasing temperatures and declining rainfall, particularly in winter and spring. A summary of the temperature and rainfall at Tambo Crossing for each of the scenarios is provided in Table 4. The most notable features are a decline in spring rainfall. (Note that Clifton Creek is not shown but has similar patterns of change).

Table 4. Long term average rainfall (mm) and temperature (°C) statistics for the Baseline and Recent scenarios, together with rainfall (percentage) and temperature (°C) changes relative to Baseline (1986-2005) for the future projections at Tambo Crossing.

Season	Baseline	Recent	2030 Mid	2030 Hot&Dry	2050 Mid	2050 Hot&Dry
Rainfall						
Summer	178 (85-271)	176 (54-302)	-1%	-19%	+1%	-11%
Autumn	134 (44-270)	140 (57-288)	-9%	-17%	-2%	-16%
Winter	160 (71-450)	167 (55- 309)	-8%	-11%	-8%	-14%
Spring	211 (106-321)	188 (95-268)	-13%	-21%	-19%	-26%
Annual	683 (450-867)	673 (472-876)				
Average temperature						
Summer	18.7	19.5	+1.1	+2.2	+1.9	+2.6
Autumn	14.3	14.8	+0.9	+1.6	+1.6	+2.4
Winter	8.9	9.3	+0.8	+1.2	+1.4	+1.8
Spring	13.3	14.2	+1.1	+2.2	+1.9	+2.7

The impact of future climate scenarios on monthly average pasture growth rates at Tambo Crossing is shown in Figure 2. Small increases in pasture growth were predicted in months of winter to early spring (June to September), but a contraction of the peak spring growing season and lower summer and autumn production was also predicted particularly in the 'hot and dry' scenarios. The impact on whole farm pasture annual pasture utilisation is shown in Figures 3 and 4. Annual pasture utilised in the median change scenarios is similar to the historic climate but declines in the 'hot and dry' scenario particularly in 2050.

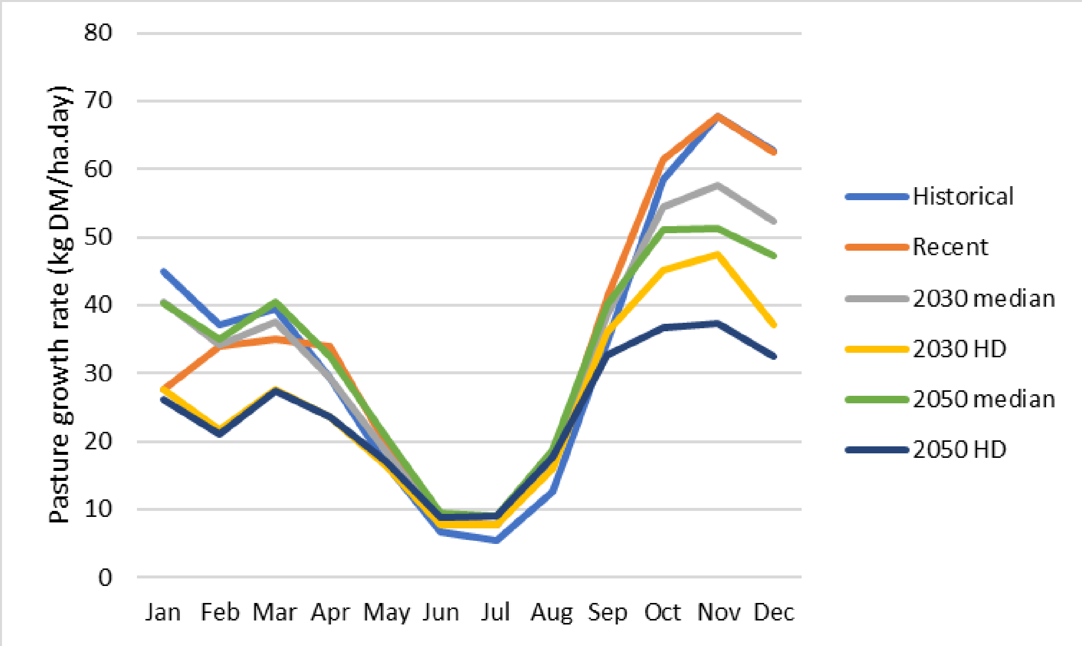


Figure 2. Monthly average pasture growth rate (kg DM/ha.day) for improved pastures at Tambo Crossing under the climate scenarios.

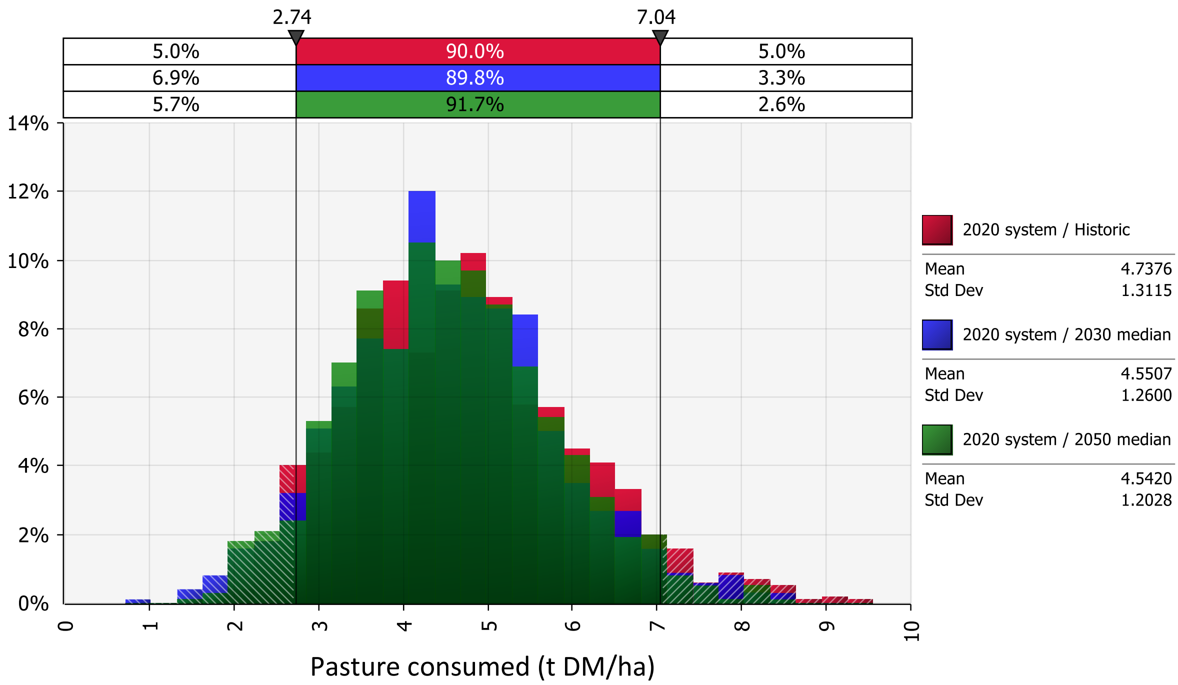


Figure 3. Annual pasture consumed (t DM/ha) for the historic, 2030, and 2050 climate scenarios in East Gippsland case study.

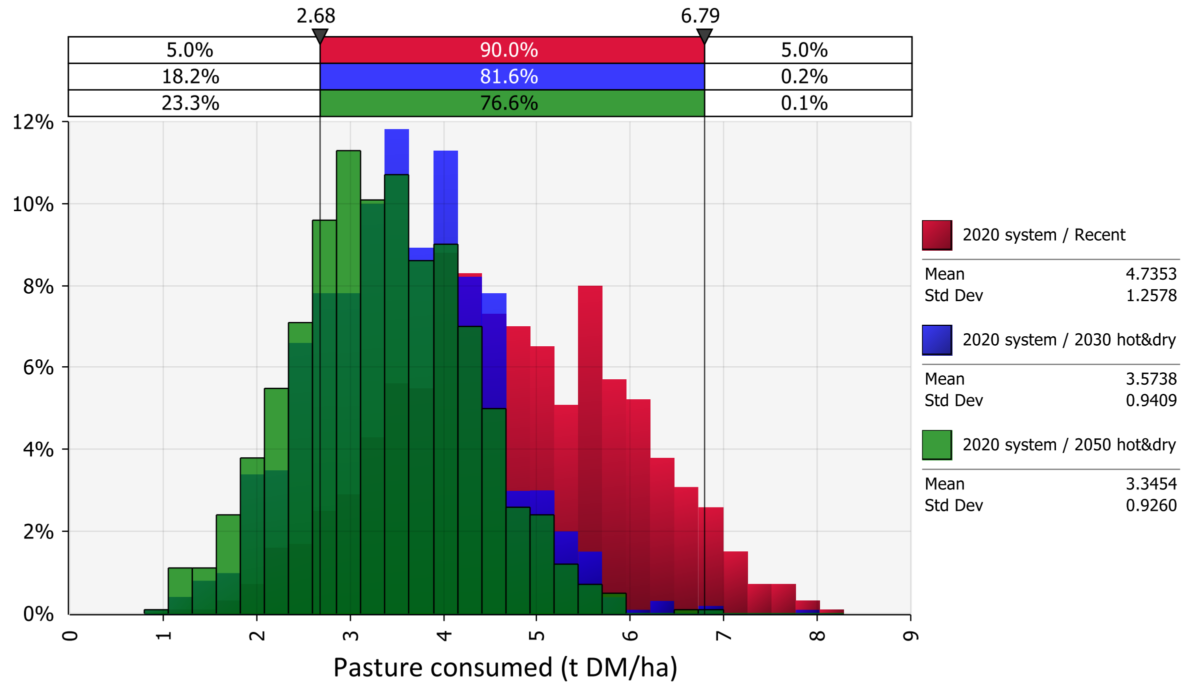


Figure 4. Annual pasture consumed (t DM/ha) for the recent 2030 hot and dry, and 2050 hot and dry climate scenarios in East Gippsland case study.

4.1.2 Future farm options

The future options defined by the regional reference groups are summarised in the Table 5.

Table 5. Summary of Base farm, Adapt, Towards Carbon Neutral and Diversify and Grow options for the East Gippsland case study.

Option	Changes implemented

Base farm (Capital value = $3.9 million)	The case study farm business has two properties (Clifton Creek and Tambo Crossing). The total effective is 600 ha and estimated overall stocking rate is approximately 18 DSE/ha. A 'steady state' livestock enterprise was as:
	• Sheep: self-replacing composite ewe flock, with 800 mature ewes and 400 ewe lambs joined per year. Lambing in July, with 150% lamb making. All wether lambs (820hd) sold in January at 44kg liveweight and 420 ewes lambs sold in May weighing 53kg liveweight.
	• Cattle: Self-replacing herd. 250 mixed age cows joined. 95% calving for mature cows and 85% for first calf heifers. Approximately 50 steers and 50 heifers sold in May (280 kg liveweight), further 70 steers sold in September (340 kg liveweight).
	• Traded livestock:
	  o Lambs: 2000 purchased in January (32 kg) and sold in April (52 kg).
	  o Cows: 40 cows with calf purchased in October and sold in May/June; calves sold at 10 months at 280kg liveweight.
	• Tree planting = 1.7 ha of shelter belts

Adapt (Capital value = $4.2 million)	1. Increase feed supply • Establish high performing perennial pastures on 225 ha at Tambo Crossing • As part of improving the pastures, paddock size will be reduced. Ten 20 ha paddocks will be created (requires fencing and water troughs) • Apply Gibberellic Acid and Urea (40 kg N/ha) on all the land that has improved pastures (406 ha) 2. Increase animal performance • Increase lambing percentage from 150 to 165% (through shelterbelts and better management of twin and triplet bearing ewes) • Genetically superior cattle: 5% improvement in animal growth rates/turnoff weights and 5% improvement in calving rates in heifers 3. Reduce greenhouse gas emissions • Sell wethers at 35kg (instead of 44kg) and sold at end of November (instead of January) • Plant 12ha of trees on unproductive areas of the farm in areas that will provide shelter to ewes bearing multiples (co-benefit).
Towards Carbon Neutral (Capital value = $5.4 million)	All changes in the 'Adapt' option plus: • Reduce livestock emissions. Feeder in paddock with all calves fed 2 kg grain/day in Feb, which increase their growth rate to 1.5kg/day and 3NOP is added to feeder. Earlier finishing. • Diversify activity mix through forestry, which can also be used to offset emissions (80ha is purchased adjacent to property). Forestry (shining gum) sequestration rate = 30.8 t CO_2e/ha per year (averaged over 25 years).
Diversify and grow (Capital value = $9.4 million)	All changes in the 'Adapt' option plus: • 410ha (400ha effective hectares, 250 ha improved and 150 ha unimproved) in Ensay stocked at 14 DSE/ha.

4.1.3 Greenhouse gas emissions

The whole farm GHG emissions and emissions intensity of sheep meat, wool and beef for all the farm options and climate scenarios are shown in Tables 6 and 7 respectively. The major emission source on the farm was enteric methane (55%) but pre-farm emissions associated with purchased livestock (mainly attributed to the trading component of the business) were also substantial at 28% (Figure 5).

In general, the climate scenarios had a minor effect on whole farm GHG emissions and emissions intensity. These effects were due to changes in the pasture utilised with additional pasture assumed to consumed by agisted animals thus increasing GHG emissions (more common in the 'Historic' climate which had higher pasture growth rates) and in the embedded emissions of additional purchased feed to make up for reduced pasture growth (more common in the 'hot and dry' scenarios).

The base farm in the Recent climate had 2701 t CO2e and relatively low emissions intensity for sheep meat and wool production due to high lambing rates and rapid lamb growth rates. The Adapt option had a small increase in total GHG emissions but lower emissions intensity due to the rise in products sold with higher animal performance. In the TCN option, the feeding strategy contributed only a small amount to reduced GHG emissions, with tree carbon sequestration essential to reduce net GHG emissions. Total emissions increased in the 'Diversify and Grow' option due to the expanded livestock business.

Of the transformational research options, the methane inhibitor had the largest impact on total GHG emissions and emissions intensity reducing emissions to approximately one-quarter of the base farm. Increased animal efficiency (achieved through lower mature size) reduced the emissions intensity of production but did not reduce total GHG because the excess pasture was consumed by agisted livestock.

Table 6. Net total farm GHG emissions (t CO_2e/year) for the East Gippsland case study in the eight farm options and six climate scenarios.

Option	Historic	Recent	2030 median	2030 Hot and Dry	2050 median	2050 Hot and Dry
Base farm	2,698	2,701	2,741	2,884	2,755	2,928
Adapt	2,719	2,731	2,623	2,532	2,583	2,606
TCN, without forestry*	2,659	2,671	2,564	2,491	2,523	2,566
TCN with 87 ha forestry	-21	-9	-116	-189	-157	-114
Grow and Diversify	4,345	4,441	4,169	3,842	4,121	3,917
Adapt with High ME pasture	3,011	3,025	2,910	2,532	2,876	2,612
Adapt with Animal Efficiency	2,721	2,735	2,625	2,477	2,585	2,551
Adapt with methane inhibitor	640	642	653	708	627	782
Adapt with Pasture, Animal and Inhibitor	709	713	719	623	695	702

Table 7. GHG emissions intensity of sheep meat, greasy wool, and beef production (t CO_2e/t product sold) for the East Gippsland case study in the eight farm options and six climate scenarios.

Option	Product	Historic	Recent	2030 median	2030 Hot and Dry	2050 median	2050 Hot and Dry
Base farm	Sheep meat	6.1	6.1	6.2	6.5	6.2	6.6
	Wool	22.5	22.6	22.9	24.1	23.0	24.5
	Beef	12.0	12.0	12.2	12.8	12.2	13.0
Adapt	Sheep meat	5.6	5.6	5.7	6.0	5.7	6.1
	Wool	20.7	20.7	21.2	22.1	21.0	22.8
	Beef	10.3	10.3	10.5	11.0	10.4	11.3
TCN without forestry	Sheep meat	5.6	5.6	5.7	6.0	5.7	6.2
	Wool	20.7	20.7	21.2	22.2	21.0	22.9
	Beef	9.5	9.5	9.8	10.2	9.7	10.5
TCN with forestry	Sheep meat	0	0	0	0	0	0
	Wool	0	0	0	0	0	0
	Beef	0	0	0	0	0	0
Adapt with High ME pasture	Sheep meat	5.9	5.9	6.1	6.2	6.0	6.4
	Wool	22.0	22.0	22.5	22.9	22.3	23.6
	Beef	10.2	10.2	10.4	10.6	10.3	10.9
Adapt with Animal Efficiency	Sheep meat	5.5	5.5	5.6	5.8	5.5	6.0
	Wool	20.2	20.2	20.7	21.5	20.5	22.2
	Beef	10.1	10.1	10.4	10.8	10.3	11.1
Adapt with methane inhibitor	Sheep meat	1.3	1.3	1.4	1.6	1.3	1.8
	Wool	4.6	4.6	5.1	6.1	4.9	6.8
	Beef	2.4	2.4	2.6	3.1	2.6	3.4
Adapt with ALL three	Sheep meat	1.3	1.3	1.4	1.5	1.4	1.7
	Wool	4.8	4.8	5.3	5.5	5.1	6.2
	Beef	2.3	2.3	2.5	2.7	2.4	3.0

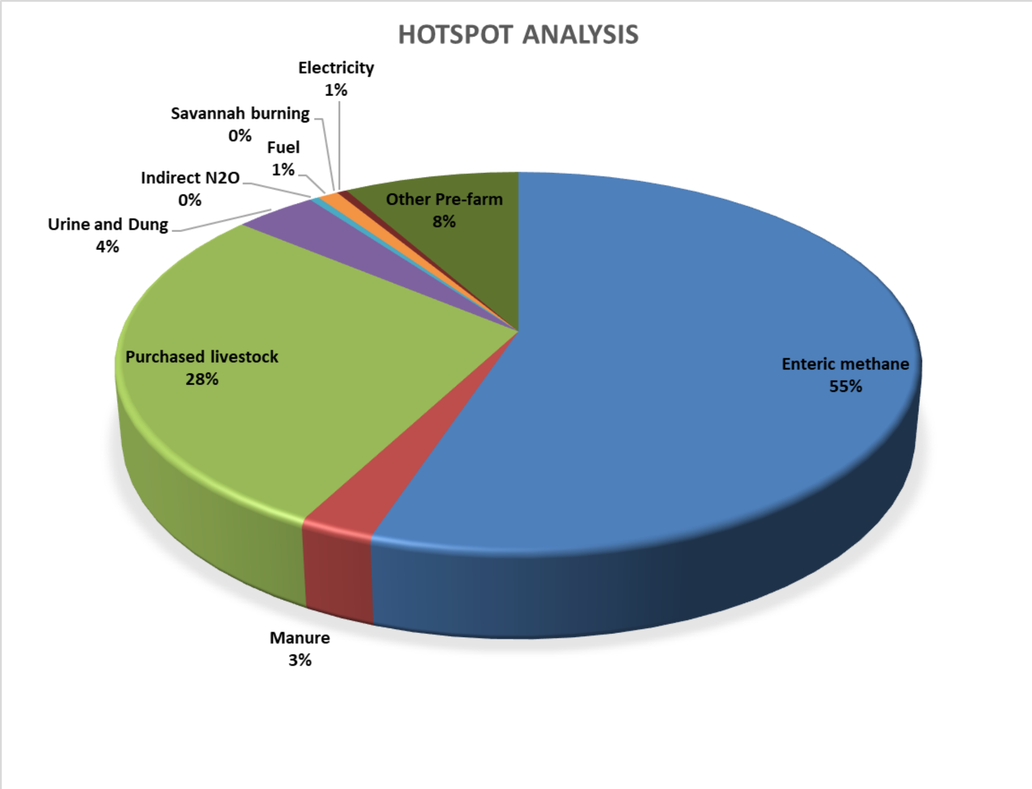


Figure 5. Percentage contribution of different sources to total farm GHG emissions of the Base farm in the East Gippsland case study in the recent climate scenario.

4.1.4 Economic performance

If the East Gippsland case study farm is run as the Base farm future (continuing the way it is run today over the next 20 years) and if the future climate reflects the modelled climate scenarios, then it is likely to be less profitable than it is today (Figure 6). The Base farm is likely to add, on average, approximately $0.5m to wealth over the 20 years (after allowing for the 7% p.a. nominal cost of the capital tied up in the farm could earn in its next best use) under the Historic climate. The change from the 'Historic' climate to the 'Recent' climate is likely to see the average addition to wealth decline by 47% and volatility to increase (the coefficient of variation of Net Present Value under the historic climate is 250% whereas under the 2050 climate it increases to 400%). If the next 20 years reflects the modelled hot and dry scenarios, then there is less than a 5% chance of this farm business earning 7% p.a nominal return.

All the other alternate farm options are likely to be better than the Base farm future (see Figure 7 – note for brevity only the distributions of NPV of each alternate farm future for the 2030 median climate change scenario is presented to demonstrate which alternate future is stochastically dominant[1]. In Figure 8 and 9 the average addition to wealth of each alternate farm future for each climate is presented).

[1] Stochastic dominance is a way of determining the superiority of one distribution over another. An option dominates, or is preferred, if it lies to the right of the cumulative distribution graph (first order dominance).

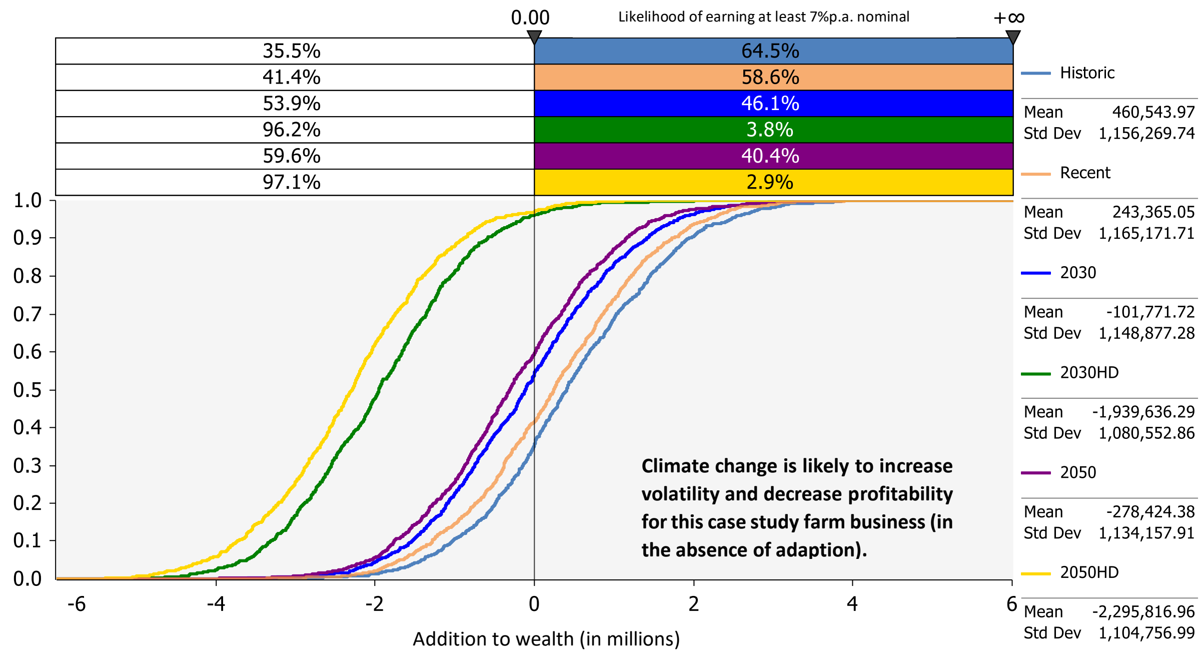


Figure 6. Likely addition to wealth (Net Present Value at 7% p.a. nominal discount rate) for the base farm under 6 different climate scenarios without a price on GHG emissions

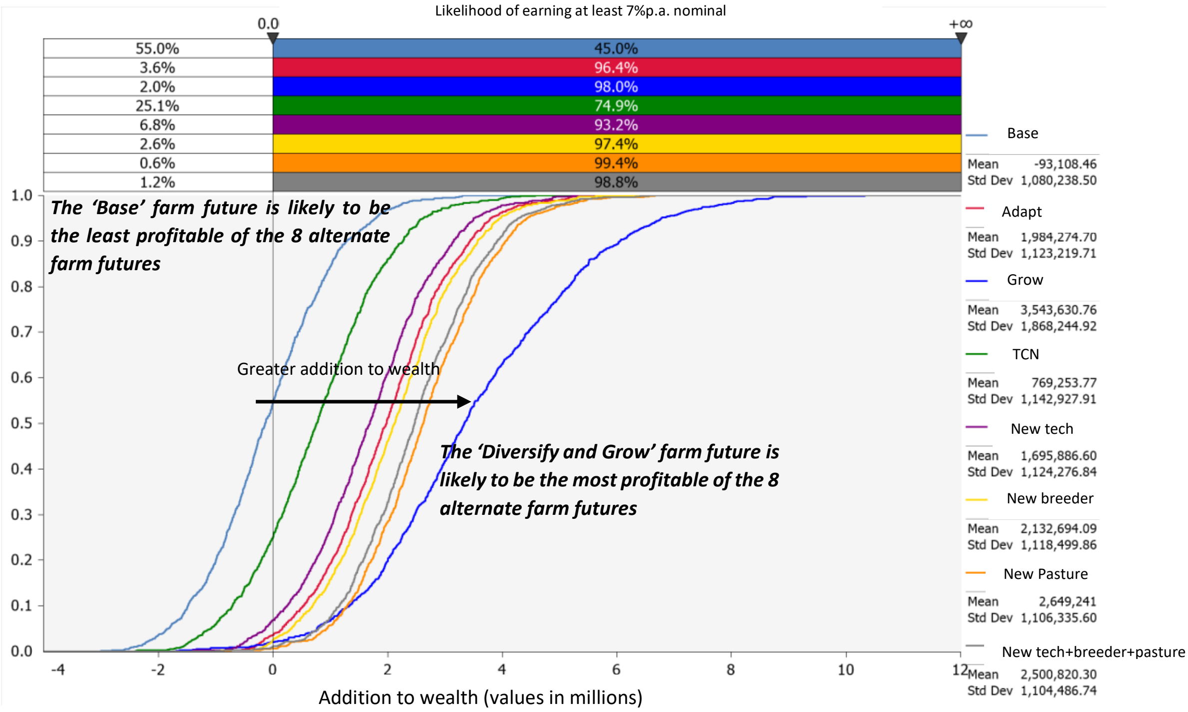


Figure 7. Likely addition to wealth over 20 years from running this farm as defined under each of the alternate futures under a 2030 median climate scenario, without a price on GHG emissions, after allowing for the 7% nominal cost of the capital tied up in the farm could earn in its next best use. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

An investment in the Adapt East Gippsland farm is likely to result in a greater addition to wealth over 20 years relative to the Base East Gippsland farm (see Figure 7 and 8) and there is a greater chance of earning at least 7% p.a. nominal return for the Adapt farm future compared to the Base farm (Table 8). For example, if the climate over next 20 years reflects the Historic climate, then on average an investment in the Adapt East Gippsland farm is likely to add $2.5 million to wealth, whereas the Base East Gippsland farm is likely to add $0.5 million with similar levels of inter-annual variability (see Figure 8). These results demonstrate that adapting to the climate by pasture improvements based on suitable species (in this case, a temperate mix but including lucerne as a summer-active mix) and increasing animal production could be key to meeting the challenge of warmer and drier climates. However, if the climate over the next 20 years reflects the modelled hot and dry climate scenario, then there is a low chance (less than 50%) that the Adapt future farm business will earn more than an alternative investment in the economy that is earning 7% p.a. nominal.

The Diversify and Grow option is likely to have the highest average addition to the wealth of all the alternative farm futures (Figure 7 and 8). This finding suggests that if capital is unconstrained, then the case study farmers would be likely to add the most to their wealth if they invested in the Diversify and Grow farm future (improve the existing farm business and increase the land area and animal numbers of the farm business). However, if the climate over the next 20 years reflects the modelled 2050 hot and dry scenarios the 'Diversify and Grow' farm future is unlikely to be better than other investments in the economy earning 7% p.a nominal (even though it is likely to be the best of alternate farm futures considered using current technology).

The TCN option is likely to be the least profitable changed farm system, as there is a cost to the farm business to reduce emissions. The average addition to wealth from the TCN option is approximately $1.2m less than the average addition to wealth from the Adapt farm system, when there is not a price on carbon.

New technology could increase the profitability of an investment in the East Gippsland farm (see Figure 9). If the case study farm has more feed efficient breeders (and these breeders have all the other attributes of the existing breeders) and/or higher quality pasture (and all other existing attributes remain) then it is likely to be more profitable relative to the 'Adapt' farm future with existing technology. Further, if the improved pasture is higher quality (with an additional 1 MJ ME/kg DM and all the other attributes of the existing species) then there is a greater chance of the investment (almost 50%) earning at least 7% p.a. nominal in the 2050 hot and dry climate. This result suggests that research and development of pasture varieties that are high in quality and quantity under hot and dry climates will be important for farm businesses to remain profitable. Unsurprisingly, the new technology of a methane inhibitor added a cost to the farm business without a corresponding benefit (when a cost on emissions was not imposed) and thus reduced the likely addition to wealth compared to the 'Adapt' only option.

Table 8. Likelihood of earning at least 7% p.a. nominal for each of the alternate futures explored, without a price on GHG emissions.

	Historic	Recent	2030 median	2030 Hot& Dry	2050 median	2050 Hot&Dry
Base	66%	58%	45%	4%	37%	2%
Adapt	99%	98%	96%	54%	97%	28%
Grow	100%	99%	98%	62%	98%	32%
TCN	87%	83%	75%	17%	73%	6%
Adapt + methane inhibitor	97%	97%	93%	44%	94%	21%
Adapt + animal efficiency	99%	99%	97%	60%	98%	33%
Adapt + new feedbase	100%	99%	99%	78%	99%	49%
Adapt + all three new technologies	100%	99%	99%	75%	99%	45%

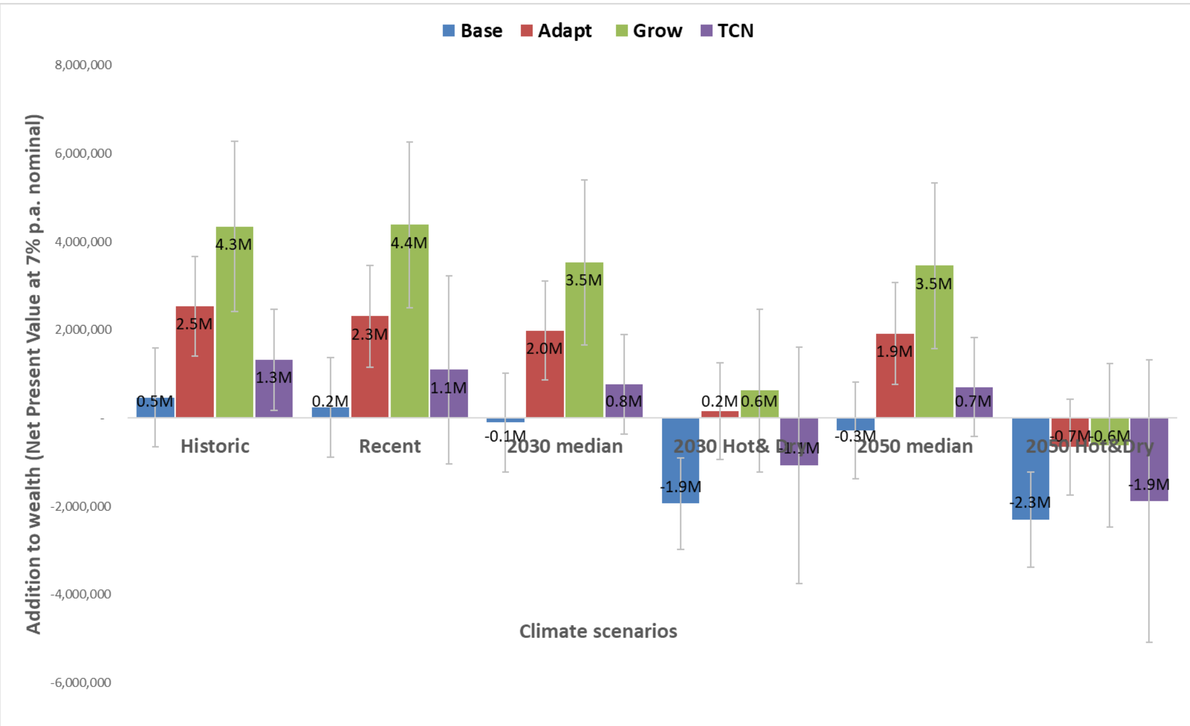


Figure 8. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the East Gippsland case study farm run in four different ways using current technology, under six climate scenarios without a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future.

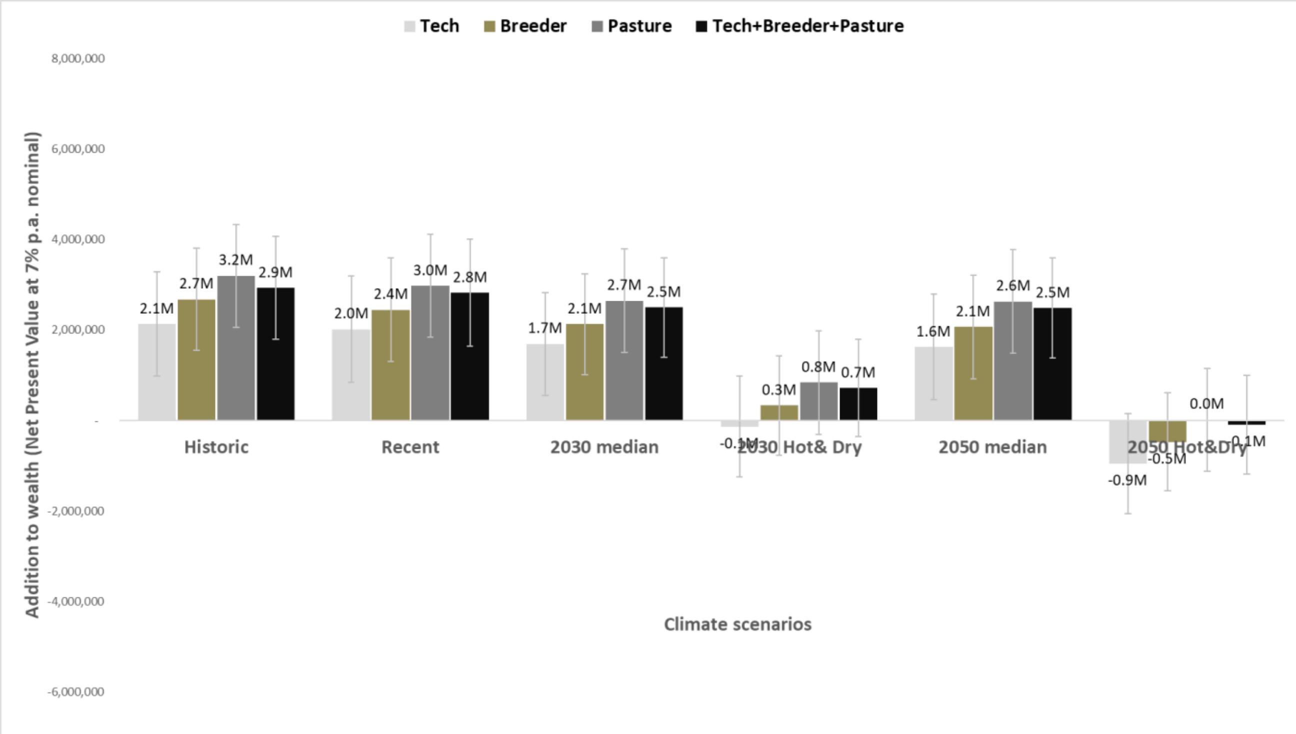


Figure 9. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the East Gippsland case study farm run in four different ways using current technology under six climate scenarios, without a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

Unsurprisingly, if the business pays their share of the social cost of carbon, then the profit of each alternate future is likely to be lower as there is now an extra cost to the farm business (Figure 10 and 11). If the East Gippsland farm was bought and run as defined under the Base farm and if it pays their share of the social cost of carbon, then it is less likely to earn 7% p.a. return (Table 9). If there was a price on GHG emissions and if the next 20 years reflects the modelled hot and dry climates then the likelihood of earning at least 7% p.a. nominal return declines for all the alternate farm futures (Table 9 and Figure 10).

If an investment in the 'Adapt' farm future includes new hypothetical methane emission reduction technology and there is a price on greenhouse gas emissions, then it is likely to be a more profitable investment than Adapt only (see Figure 10 and 11). Further, if the farm pays their share of the social cost of carbon and the breeders are more feed efficient, and the pastures are higher in quality and there is new technology that reduces methane by 80% then the average addition to wealth is likely to be as much wealth as the Diversify and Grow future farm scenario; highlighting the importance of research and development under such changed conditions.

Table 9. Likelihood of earning at least 7% p.a. nominal for each of the alternate futures explored, with a price on GHG emissions.

	Historic	Recent	2030 median	2030 Hot& Dry	2050 median	2050 Hot&Dry
Base	24%	30%	14%	0%	12%	0%
Adapt	87%	91%	81%	23%	79%	7%
Grow	93%	94%	87%	31%	84%	15%
TCN	83%	87%	75%	17%	73%	6%
Adapt + methane inhibitor	95%	96%	90%	36%	89%	14%
Adapt + animal efficiency	90%	93%	84%	29%	82%	10%
Adapt + new feedbase	95%	96%	93%	44%	93%	19%
Adapt + all three new technologies	99%	99%	98%	67%	98%	37%

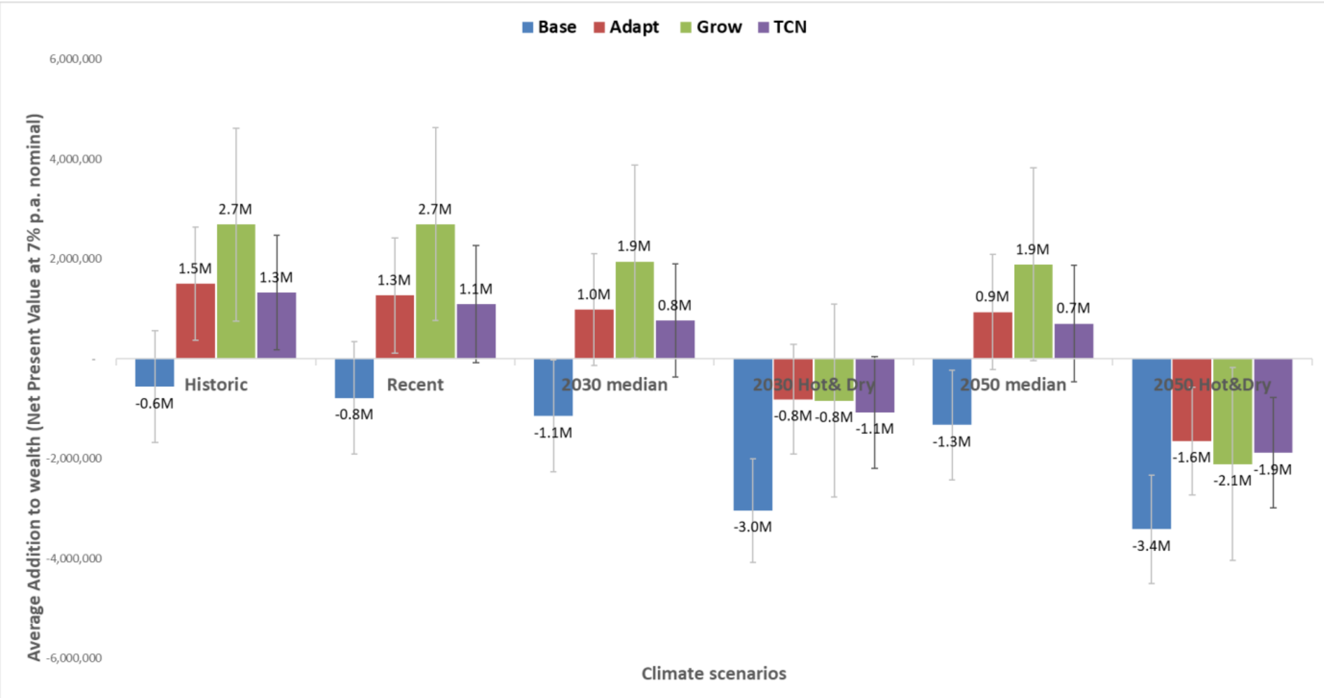


Figure 10. Average addition to wealth (Net Present Value at 7% p.a. nominal) for East Gippsland case study for the four farm futures based on existing technology under six climate scenarios, with a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future.

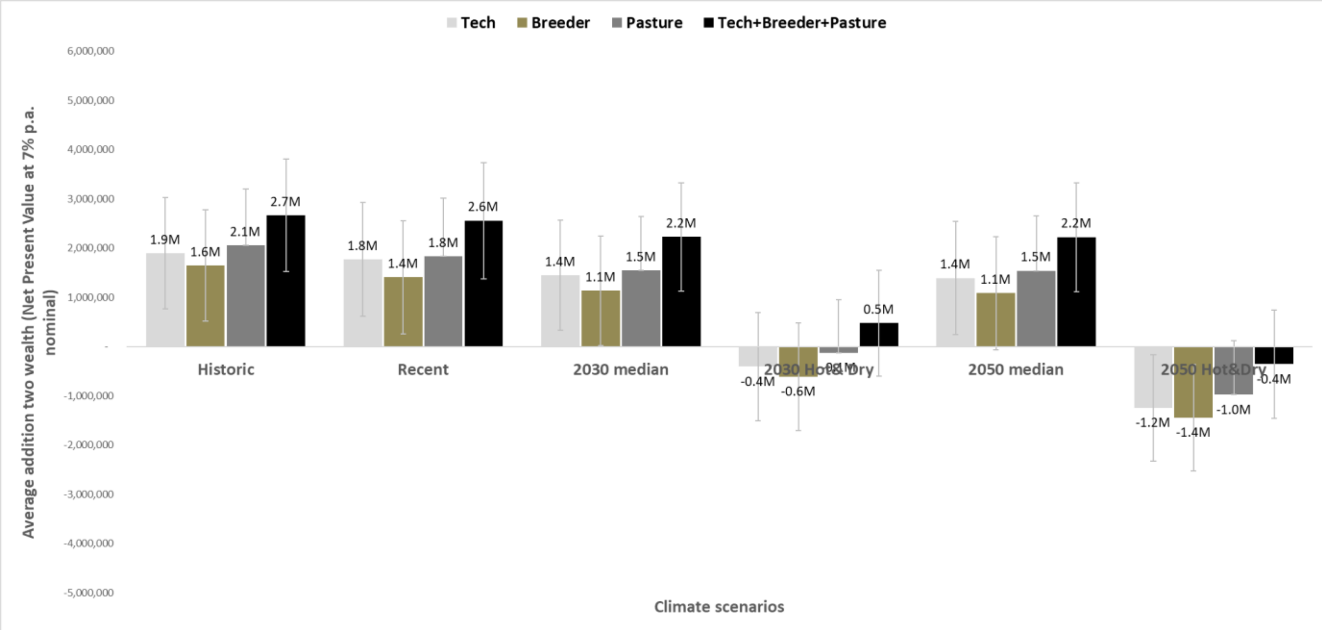


Figure 11. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the East Gippsland case study for four farm futures based on hypothetical future technology under six climate scenarios, with a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

Financial Results East Gippsland

If the Base farm has 85% equity and if the case study farmer has to increase borrowings to change the farm business (in the ways described earlier) then debt servicing obligations will increase (Table 10).

Table 10. Total Capital investment, equity percentage, debt and annual debt servicing obligations for each of the East Gippsland case study farm alternate farm futures (Terms of the amortised loan: 15 years and 7% interest)

	Total capital investment	Equity %	Debt	Annual debt servicing obligations
Base	3,913,400	85%	587,010	64,451
Adapt	4,255,118	78%	936,126	102,782
Grow	9,431,118	50%	4,715,559	517,743
TCN	5,384,141	63%	1,992,132	218,725
Adapt + methane inhibitor	4,255,118	78%	936,126	102,782
Adapt + animal efficiency	4,255,118	78%	936,126	102,782
Adapt + new feedbase	4,255,118	78%	936,126	102,782
Adapt + all three new technologies	4,255,118	78%	936,126	102,782

The more debt servicing obligations increase, the greater the risk of negative net cash flows and thus the greater the total risk the business faces. In Figure 12 and 13, annual net cash flow with and without debt servicing is represented. As highlighted with the red arrows, there is a greater decline in the likelihood of annual net cash flow being positive for the Grow farm future (without debt the likelihood of a positive annual net cash flow is around 90%, with debt the likelihood of positive annual net cash flow is around 40%). This reiterates the importance of considering an investment from the economic and financial perspectives. Finance matters. Although the Grow farm future is likely to add the most to wealth, it is also the option with the highest capital investment and could have the highest debt servicing obligations. In deciding which farm future is the 'best' for the case study farmers it also depends on their equity and their attitude to risk.

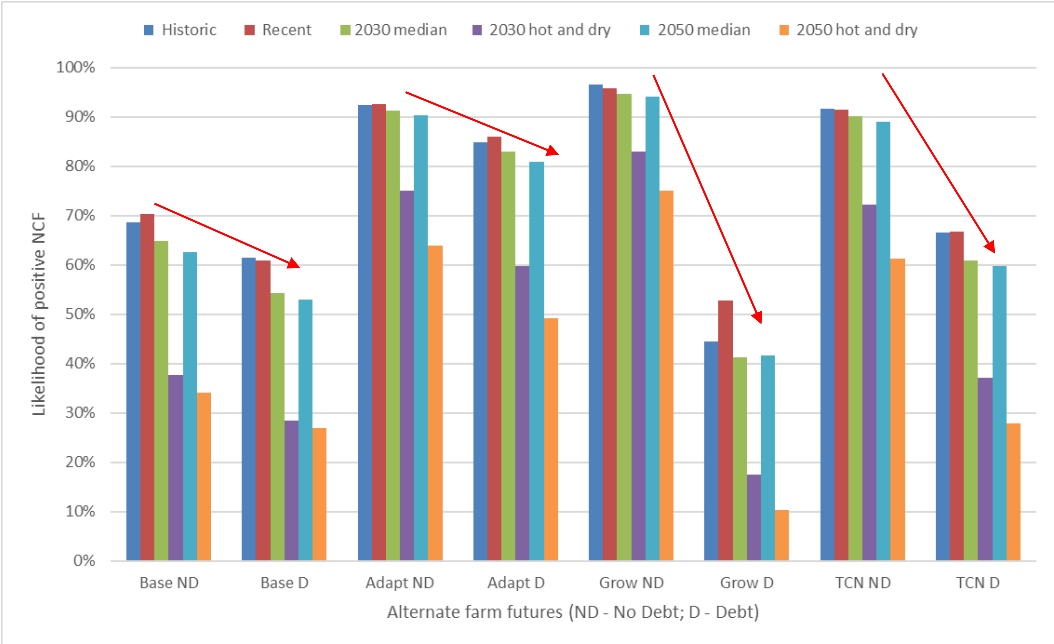


Figure 12. Likelihood of positive net cash flow for each of the alternate farm futures based on existing technology with and without debt. Each arrow highlights the reduced likelihood of positive net cash flows from borrowings.

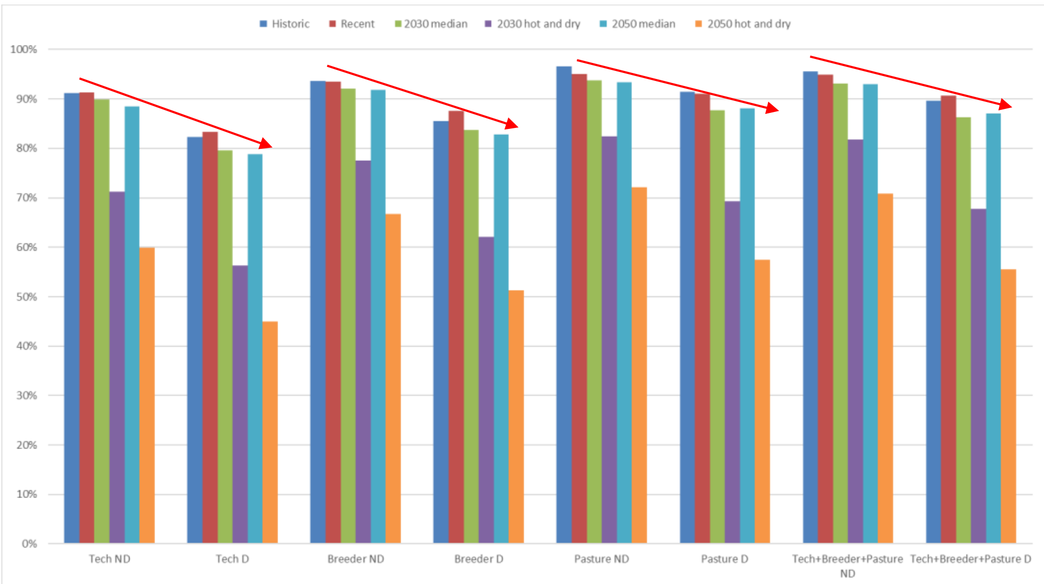


Figure 13. Likelihood of positive net cash flow for each of the alternate farm futures based on future possible technology with and without debt. Each arrow highlights the reduced likelihood of positive net cash flows from borrowings.

4.2 Northern Victoria

4.2.1 Impacts of Future climates on pasture production

A summary of the temperature and rainfall for each of the scenarios is provided in Table 11. The most notable features are a decline in spring rainfall and increasing temperature. (Note that Strathbogie is not shown but has similar patterns of change). Average annual rainfall at Violet Town was 663, 561, 599, 526, 565 and 517 mm in the Historic, Recent, 2030 Median, 2030 Hot&Dry, 2050 Median and 2050 Hot&Dry scenarios, respectively.

Table 11. Long term average rainfall (mm) and temperature (°C) statistics for the Baseline and Recent scenarios, together with rainfall (percentage) and temperature (°C) changes relative to Baseline (1986-2005) for the future projections at Violet Town.

Season	Baseline	Recent	2030 Mid	2030 Hot&Dry	2050 Mid	2050 Hot&Dry
Rainfall						
Summer	114	132	-2%	-25%	-3%	-5%
Autumn	139	115	-6%	-21%	-10%	-22%
Winter	227	181	-10%	-17%	-16%	-24%
Spring	184	133	-15%	-20%	-22%	-28%
Annual	663	561				
Average temperature						
Summer	21.0	21.9	+1.1	+1.8	+2.1	+2.9
Autumn	15.1	15.3	+1.0	+1.3	+1.8	+2.5
Winter	8.6	8.5	+0.8	+0.9	+1.3	+1.6
Spring	13.9	14.5	+1.4	+1.8	+2.4	+3.1

Pasture production was simulated for each climate scenario using the SGS Pasture model. A sown temperate pasture mix was simulated. The 2030 and 2050 climate scenarios show an increase in winter pasture production and a contraction of the spring growing season (Figure 14). The impacts on pasture production are larger under the 'hot and dry' climate scenarios compared to the 'median', and the impacts are greater in 2050 compared to 2030. These changes are reflected in the pasture consumed distributions (Figures 15-16) where pasture consumed was lowest in the 2050 'hot and dry' scenario.

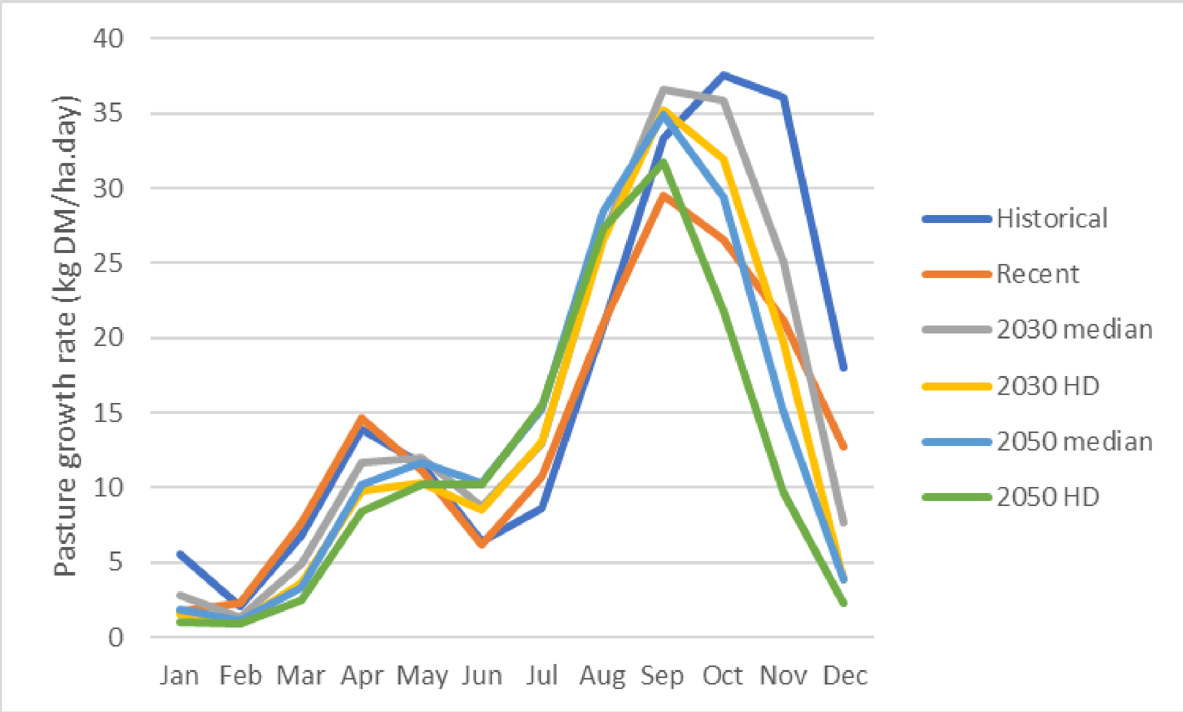


Figure 14. Predicted monthly pasture harvested (kg DM/ha) at Violet Town under the climate scenarios.

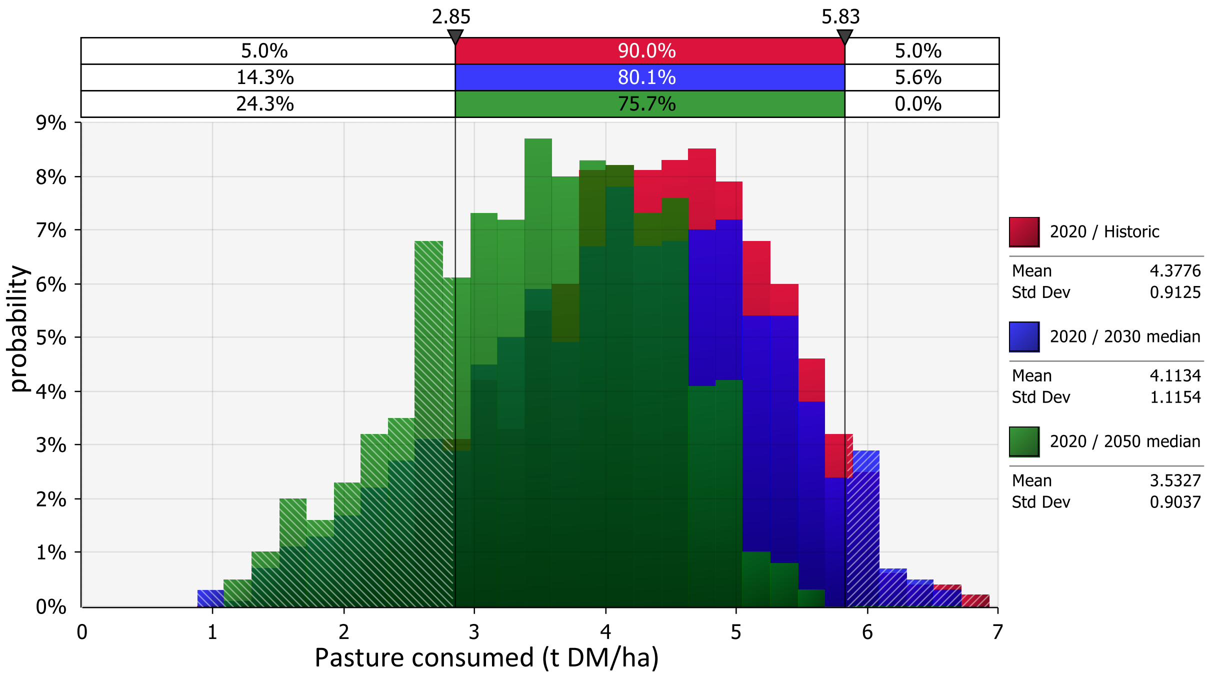


Figure 15. Probability distribution of the pasture consumed (t DM/ha) for the historic, 2030, and 2050 climate scenarios in northern Victoria case study.

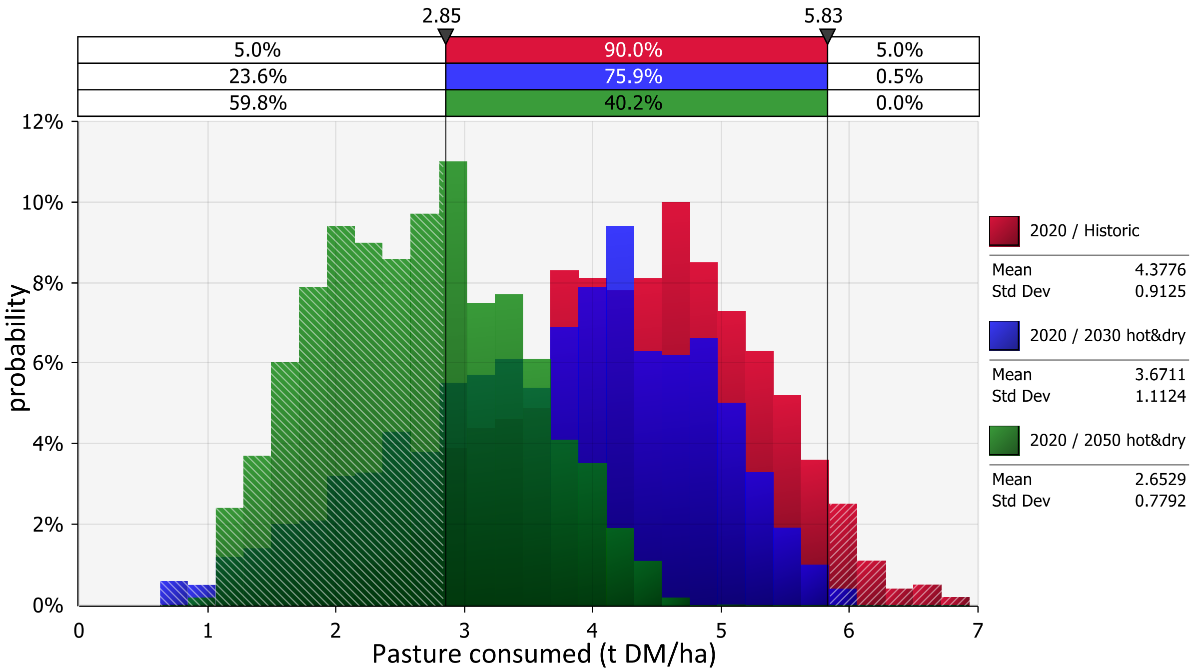


Figure 16. Probability distribution of the t DM grown and consumed/ha.annum for the historic, 2030 hot and dry, and 2050 hot and dry climate scenarios in the northern Victoria case study.

4.2.2 Future farm options

The future options defined by the regional reference groups are summarised in Table 12.

Table 12. Summary of Base farm, Adapt, Towards Carbon Neutral and Diversify and Grow options for the northern Victoria case study.

Option	Changes implemented
Base Farm (capital value = 12.5 million)	The case study farm business has two properties (Violet Town and Strathbogie). The effective area used for grazing is 1251 ha at Violet Town and 223 ha at Strathbogie. A 'steady state' livestock enterprise was defined as: • Sheep: self-replacing composite ewe flock. 3145 mature ewes (at Violet Town, July lambing, 140% lamb marking) and 617 ewe lambs (at Strathbogie, August lambing, 110% lamb marking) joined per year. All wether lambs were sold in December/January, replacements kept. • Cattle: Self-replacing herd. 300 mixed age cows joined. 95% weaning. Steers and surplus heifers sold at 14-15 months (480 kg liveweight). Pasture is predominantly phalaris, annual grass and subclover, with 100 ha of unimproved pasture (annual grasses, clover) at Violet Town.
Adapt (capital value = $15.5 million)	1. Increase feed supply • Establish high performing perennial pastures on 100 ha at Violet Town • As part of improving the pastures, paddock size will be reduced. • Purchase 200 ha improved land in Violet Town (reduce stocking rate) • Apply Gibberellic Acid and Urea (40 kg N/ha) on all the land that has improved pastures (837 ha) 2. Increase animal performance • Increase lambing percentage from 140 to 155% (through shelterbelts and better management of twin and triplet bearing ewes) • Move lambing and calving a month earlier and sell one month earlier 3. Reduce greenhouse gas emissions • Plant 10 ha of trees on unproductive areas of the farm in areas that will provide shelter to ewes bearing multiples (co-benefit).

Towards Carbon Neutral (capital value = $20.1 million)	All changes in the 'Adapt' option plus:
	• Reduce livestock emissions:
	  o Wean steers then finish in containment area: aim so that can feed an additive to reduce their methane emissions by 70% with 3-NOP + higher growth rates so turnoff earlier
	  o Replacement ewe lambs will be fed in containment feeding for the two months of summer (November and December). With a 5% increase in the lambing percentage
	• Diversify activity mix through forestry, which can also be used to offset emissions. It is assumed 220ha is purchased and will be used for forestry as well as to offset carbon emissions from the farm business. Forestry (shining gum) sequestration rate = 18.8 t CO_2e/ha per year (averaged over 25 years).

Diversify and grow (capital value = $23.0 million)	All changes in the 'Adapt' option plus: • 400 ha of phalaris/clover pasture was purchased in south-west Victoria (Carpendeit, to expand and provide spatial diversification) and stocked at 18 DSE/ha.

4.2.3 Greenhouse gas emissions

The whole farm GHG emissions and emissions intensity of sheep meat, wool and beef for all the farm northern Victoria options and climate scenarios are displayed in Tables 13 and 14, respectively. The major emission source on the Base farm was enteric methane (84%) (Figure 17).

The climate scenarios had a moderate effect on whole farm GHG emissions and emissions intensity due to changes in the pasture utilised. The additional pasture was assumed to be consumed by agisted animals, thus increasing GHG emissions (more common in the 'Historic' climate, which had higher pasture growth rates) and in the embedded emissions of additional purchased feed to make up for reduced pasture growth (more common in the 'hot and dry' scenarios).

The base farm in the Recent climate had 3538 t CO2e and relatively low emissions intensity for sheep meat and wool production due to high lambing rates and rapid lamb growth rates. The Adapt option had a small increase in total GHG emissions but lower emissions intensity due to an increase in products sold with higher animal performance. In the TCN option, the feeding strategy contributed only a small amount to reduced GHG emissions, with tree carbon sequestration essential to reduce net GHG emissions. Total emissions increased in the 'Diversify and Grow' option due to the expanded livestock business.

Of the transformational research options, the methane inhibitor had the largest impact on total GHG emissions and emissions intensity reducing emissions to 31% of the Adapt farm. Increased animal efficiency (achieved through lower mature size) reduced the emissions intensity of production but did not reduce total GHG because the excess pasture was consumed by agisted livestock.

Table 13. Net total farm GHG emissions (t CO_2e/year) for the northern Victoria case study in the eight farm options and six climate scenarios.

Option	Historic	Recent	2030 median	2030 Hot and Dry	2050 median	2050 Hot and Dry
Base farm	3924	3538	3604	3510	3584	3899
Adapt	4644	3629	4293	3751	3471	3806
TCN	803	-212	452	-94	-370	-456
Grow and Diversify	7134	5654	6392	5605	5368	5230
Adapt with New pasture	3824	3614	4438	3784	3908	3620
Adapt with Animal Efficiency	4572	3557	4221	3678	3399	3528
Adapt with methane inhibitor	2183	1168	1832	1290	1010	1345
Adapt with Pasture, Animal and Inhibitor	1449	1239	2063	1414	1533	1038

Table 14. GHG emissions intensity of sheep meat, greasy wool, and beef production (t CO_2e/t product sold) for the northern Victoria case study in the eight farm options and six climate scenarios. (tbc = to be completed)

Option	Product	Historic	Recent	2030 median	2030 Hot and Dry	2050 median	2050 Hot and Dry
Base farm	Sheep meat	7.4	7.6	7.4	7.6	7.7	8.3
	Wool	26.8	27.5	26.8	27.4	27.8	29.8
	Beef	9.5	10.0	9.5	9.9	10.1	11.3
Adapt	Sheep meat	7.2	7.2	7.2	7.2	7.2	7.8
	Wool	26.1	26.1	26.1	26.1	26.1	28.0
	Beef	9.3	9.3	9.3	9.3	9.3	10.6
TCN	Sheep meat	0	0	0	0	0	0
	Wool	0	0	0	0	0	0
	Beef	0	0	0	0	0	0
Adapt with New pasture	Sheep meat	7.2	7.2	7.2	7.2	7.2	7.8
	Wool	26.1	26.1	26.1	26.1	26.1	28.0
	Beef	9.3	9.3	9.3	9.3	9.3	10.6
Adapt with Animal Efficiency	Sheep meat	6.6	6.6	6.6	6.6	6.6	7.1
	Wool	23.9	23.9	23.9	23.9	23.9	25.6
	Beef	9.0	9.0	9.0	9.0	9.0	10.1
Adapt with methane inhibitor	Sheep meat	2.1	2.1	2.1	2.1	2.1	2.7
	Wool	7.6	7.6	7.6	7.6	7.6	9.6
	Beef	2.7	2.7	2.7	2.7	2.7	3.9
Adapt with ALL three	Sheep meat	1.9	1.9	1.9	1.9	1.9	2.1
	Wool	7.0	7.0	7.0	7.0	7.0	7.6
	Beef	2.6	2.6	2.6	2.6	2.6	2.9

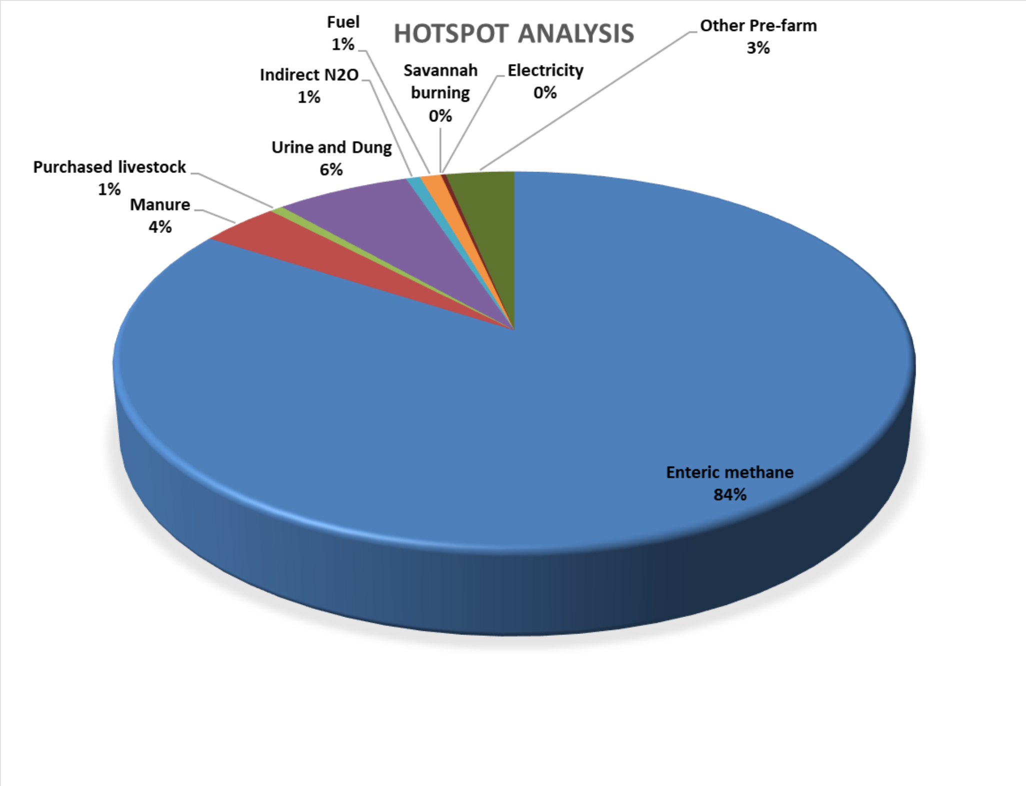


Figure 17. Percentage contribution of different sources to total farm GHG emissions of the Base farm in the northern Victorian case study in the recent climate scenario.

4.2.4 Economic performance

Economic Results Northern Victoria

The economic performance of the Base farm is likely to be negatively impacted by the future climate scenarios (in the absence of adaptation) but it is still likely to be a profitable investment unless the modelled 2050 hot and dry climate scenario occurs (see Figure 18). The base farm is likely to add, on average, $5.9m to wealth over the 20 years (after allowing for the 7% p.a. nominal cost of the capital tied up in the farm could earn in its next best use) under the Historic climate (Table 16). If the climate over the next 20 years reflects the Recent climate, instead of the Historic climate, it is likely that annual addition to wealth could decline by 55%.

If the farm was run in the other alternate ways defined in Table 12, it is generally likely these could be more profitable than the base farm, the only exception is the TCN scenario that reduces greenhouse gas emissions in the absence of a price on carbon (see Figure 19 – note for brevity only the distributions of NPV of each alternate farm future for the 2030 median climate change scenario is presented to demonstrate which alternate future is stochastically dominant. In Figures 20 and 21 the average addition to wealth of each alternate farm future for each climate is presented).

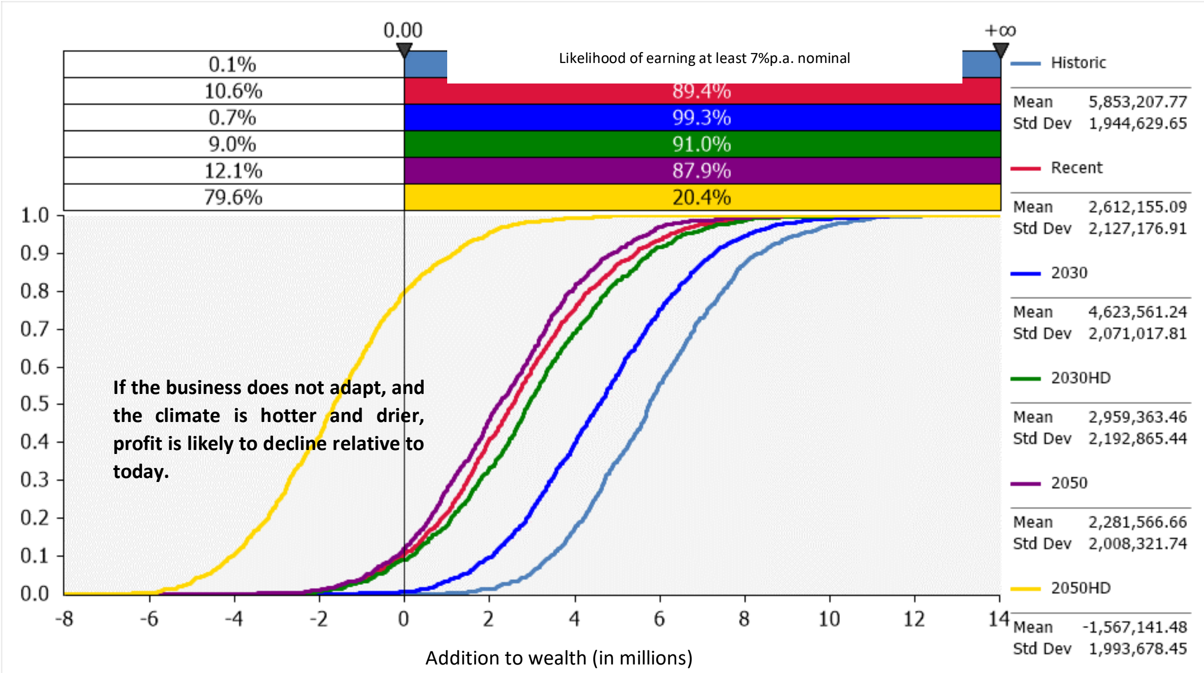


Figure 18. Likely addition to wealth (Net Present Value at 7% p.a. nominal discount rate) for the base farm under 6 different climate scenarios without a price on GHG emissions

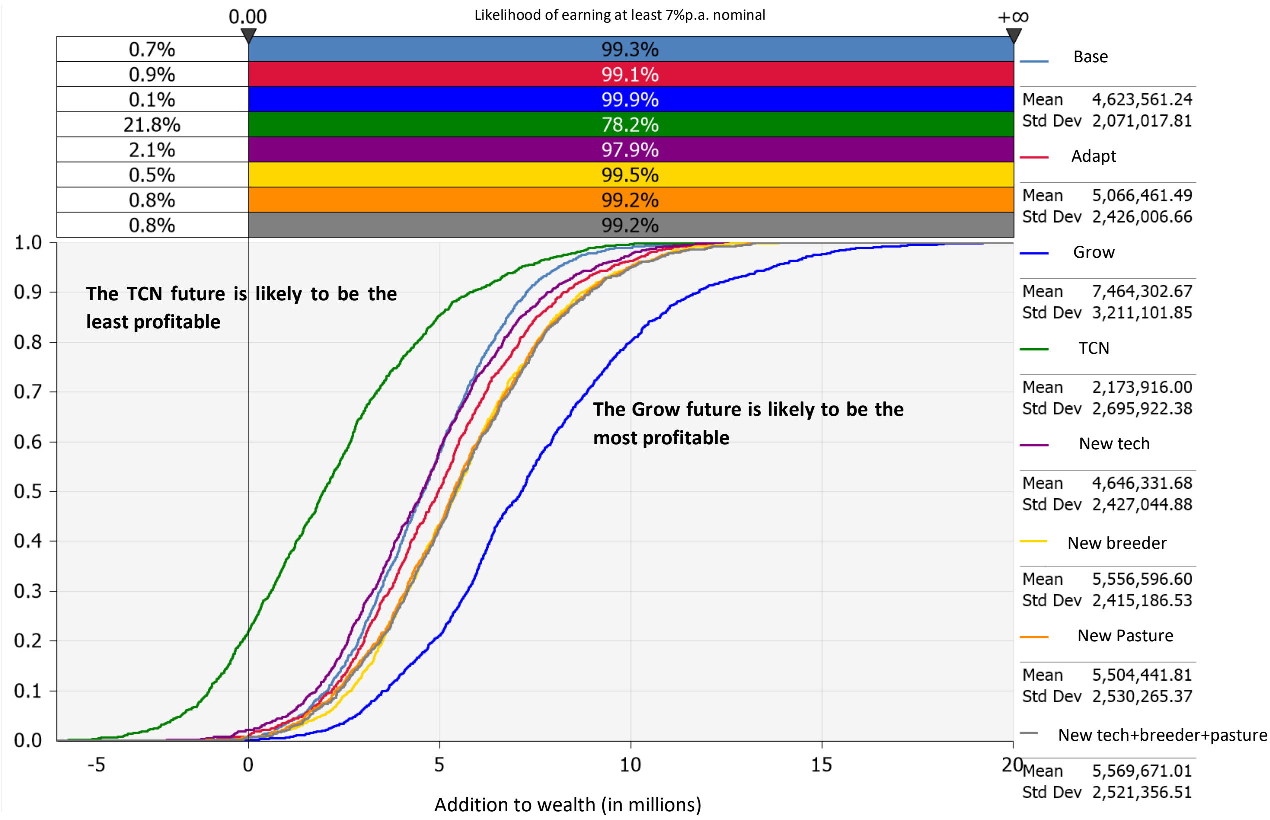


Figure 19. Likely addition to wealth over 20 years from running this farm as defined under each of the alternate futures under a 2030 median climate change scenario, without a price on GHG emissions, after allowing for the 7% p.a. nominal cost of the capital tied up in the farm could earn in its next best use. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

The Adapt farm future is likely to be more profitable than the Base option of the Northern Victoria farm business. The mean addition to wealth over the 20 years from the Adapt farm, if there is the Historic climate, is $6.3 million compared to $5.9 million for the Base farm with similar levels of inter-annual variability (Table 16). Further, there is a higher chance of earning a 7% p.a. nominal return or more for the Adapt farm future in any of the climate scenarios (as seen in table 17). These results demonstrate that adapting to a change in climate through pasture improvements based on suitable species and increasing animal production are key to meeting the challenge of warmer and drier climates. However, under the modelled 2050 hot and dry scenario, there is less than 40% chance that the farm business will earn more than an alternative investment in the economy that is earning 7% p.a. nominal (Table 17). Thus, other changes will be required to make this farm a profitable investment if this climate scenario eventuates.

The 'Diversify and Grow' option is likely to have the highest average addition to the wealth of all the alternative farm futures investigated (Figure 20). In all climate scenarios, except the 2050 hot and Dry scenario, the 'Diversify and Grow' farm future is likely to be more profitable than other investments in the economy, earning a 7% p.a. nominal return (Table 15). In the 2050 hot and dry scenario, there is a 30% chance that this farm future will earn 7% p.a. nominal or more.

The TCN option is likely to be the least profitable way to run this farm business as there is a cost to the farm business to reduce emissions (mean NPV was approximately $2.8 million lower, Figure 20 and Table 15).

Of the hypothetical transformational technologies, the new pasture variety is likely to result in greater wealth than the Adapt scenario in the 2030 and 2050 median and hot and dry climate scenarios, but less wealth in the Historic climate scenario (Figure 21 and Table 16). The methane inhibitor is likely to add a cost to the farm business without a corresponding benefit (when a cost on emissions was not imposed, as displayed in Table 15) and thus reduced the likely addition to wealth compared to the Adapt option.

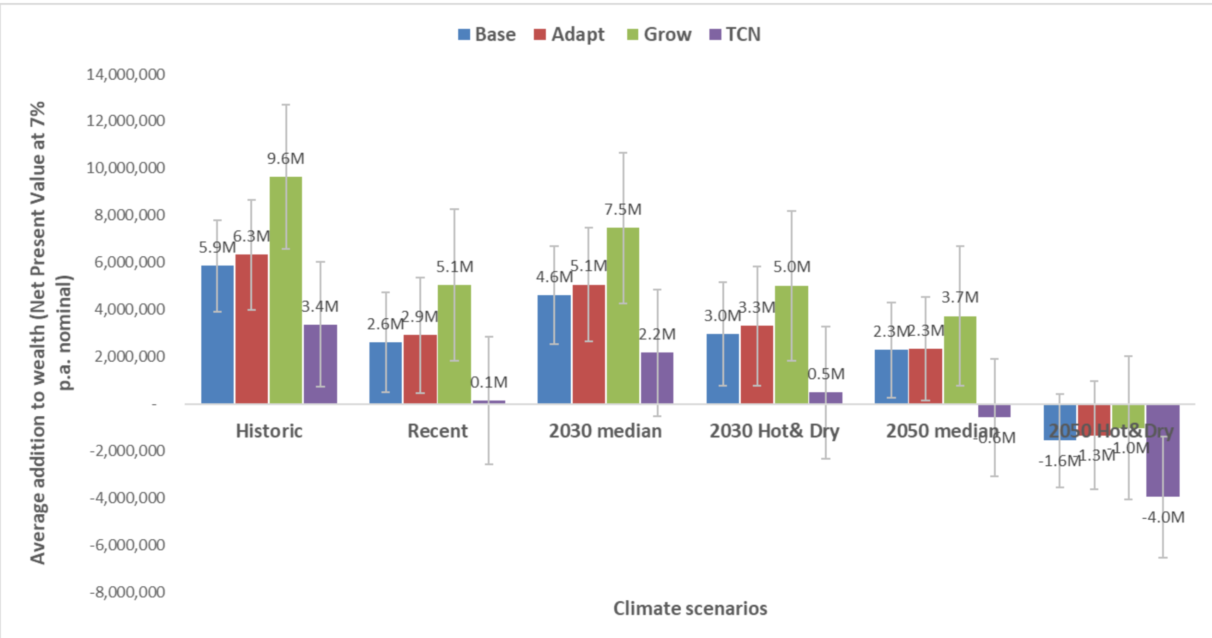


Figure 20. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the Northern Victoria case study farm, run in four different ways using current technology under six climate scenarios without a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future.

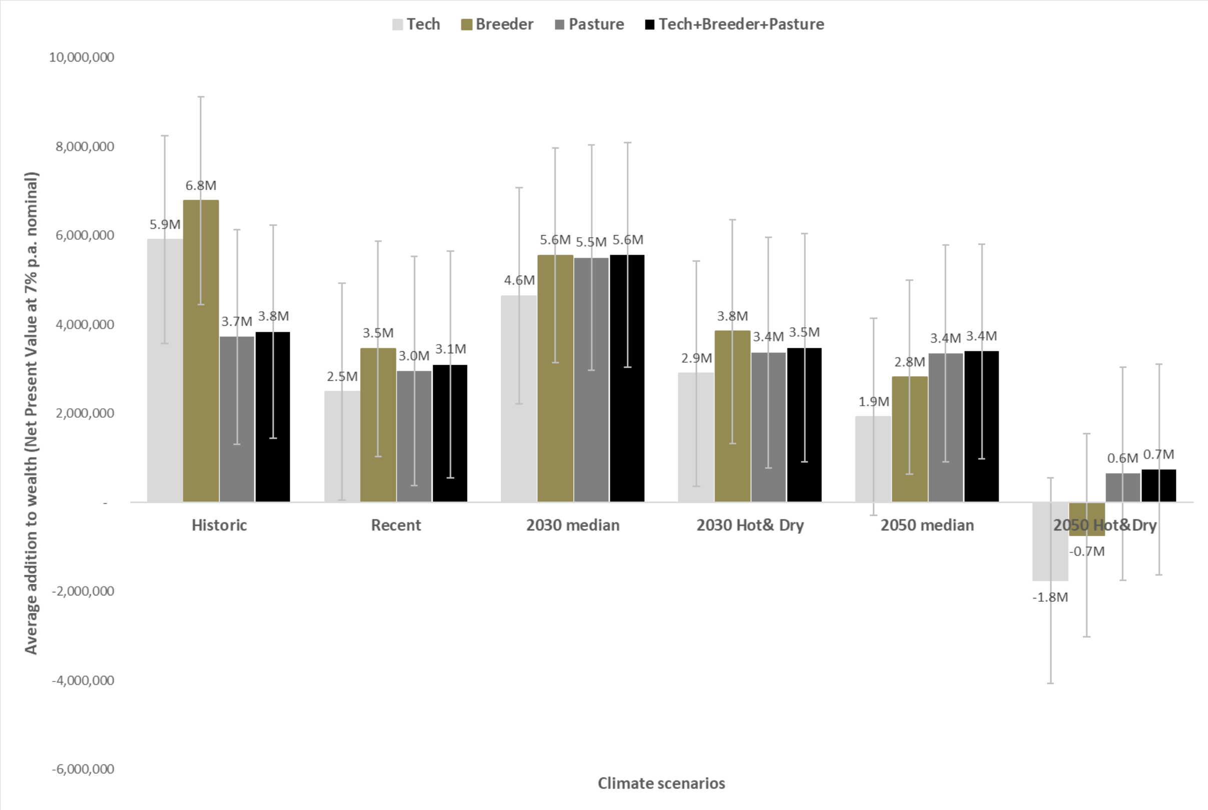


Figure 21. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the Northern Victoria case study farm, run in four different ways using hypothetical future technology under six climate scenarios without a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

Table 15. Likelihood of Northern Victoria case study farm earning at least 7% p.a. nominal for each of the alternate futures explored, without a price on GHG emissions.

	Historic	Recent	2030 median	2030 Hot& Dry	2050 median	2050 Hot&Dry
Base	100%	89%	99%	91%	88%	20%
Adapt	100%	89%	99%	91%	86%	26%
Grow	100%	96%	100%	96%	92%	32%
TCN	91%	48%	78%	53%	36%	8%
Adapt + methane inhibitor	100%	85%	98%	88%	80%	21%
Adapt + animal efficiency	100%	94%	99%	95%	92%	34%
Adapt + new feedbase	96%	88%	99%	91%	93%	61%
Adapt + all three new technologies	96%	89%	99%	92%	94%	63%

It is likely that profit would decline if the Northern Victoria case study farm pays their share of the social cost of carbon relative to if they did not pay this cost (Table 16 and Figure 22). This highlights that the social cost of carbon is another cost farm businesses will have to manage. If there is new technology available that reduces methane emissions cheaply, then it is likely that the farm business would add more to wealth through adopting this hypothetical technology than adapting and paying their share of the social cost of carbon. Further, in all future climate scenarios, there is a good chance that the Adapt farm plus the combination of new technologies will be as profitable (or more profitable) than alternate investments in the economy (Table 16 and Figure 23).

Table 16. Likelihood of earning at least 7% p.a. nominal for each of the alternate futures explored, with a price on GHG emissions.

	Historic	Recent	2030 median	2030 Hot& Dry	2050 median	2050 Hot&Dry
Base	99%	73%	95%	77%	66%	7%
Adapt	99%	73%	94%	78%	67%	11%
Grow	100%	83%	97%	82%	70%	16%
TCN	89%	48%	76%	53%	36%	8%
Adapt + methane inhibitor	100%	80%	96%	84%	75%	16%
Adapt + animal efficiency	99%	81%	96%	84%	75%	17%
Adapt + new feedbase	83%	73%	94%	78%	76%	36%
Adapt + all three new technologies	92%	85%	98%	88%	88%	56%

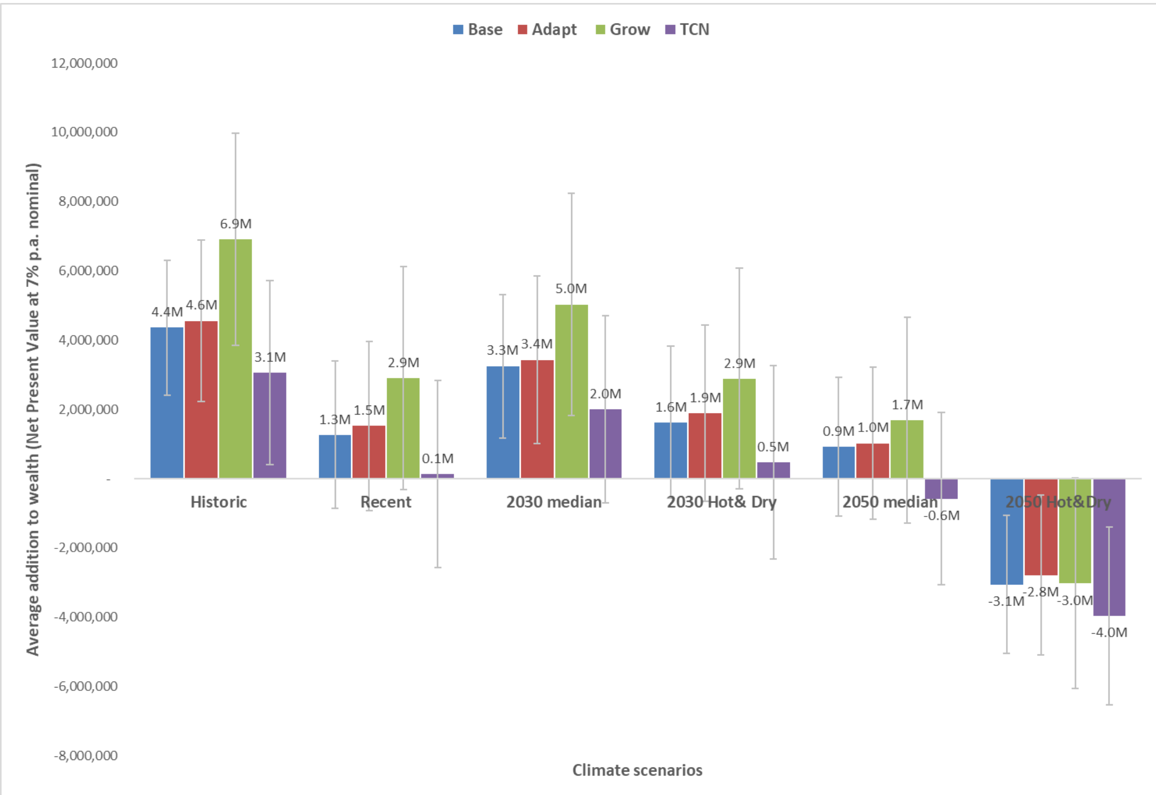


Table 22. Average addition to wealth (Net Present Value at 7% p.a. nominal) Northern Victoria case study farm, run in four different ways using current technology under six climate scenarios with a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future.

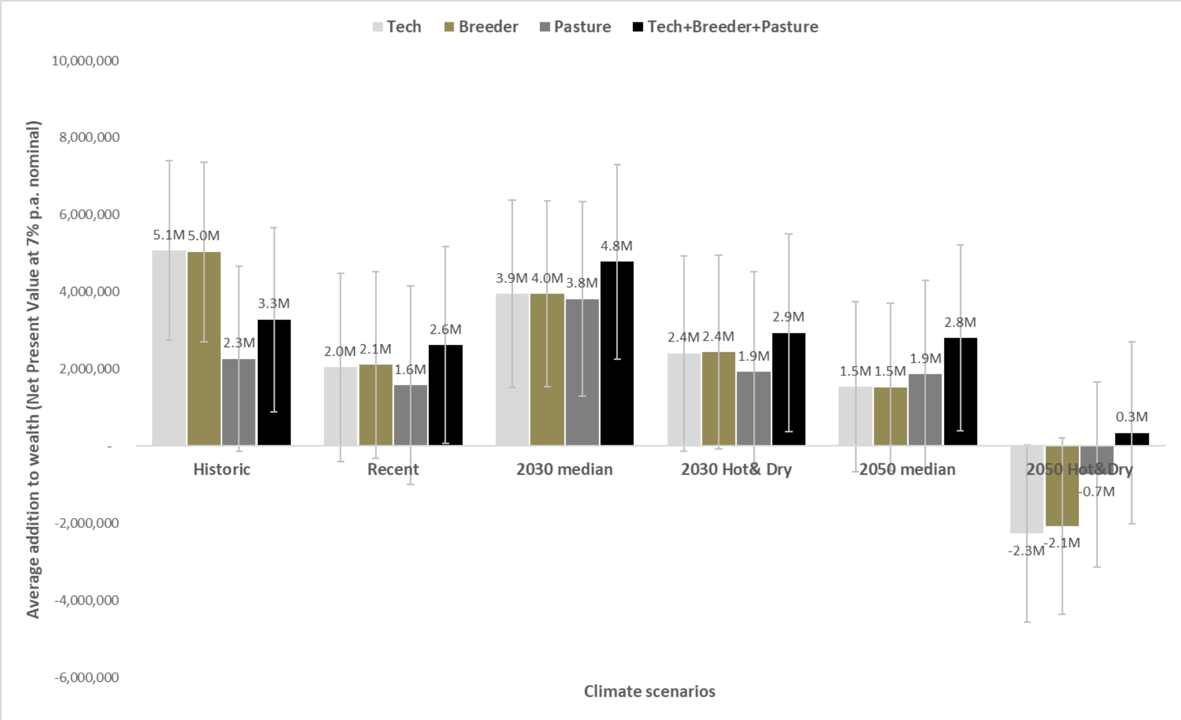


Figure 23. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the Northern Victoria case study farm, run in four different ways using hypothetical future technology under six climate scenarios with a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

Financial Results Northern Victoria

If the Base farm has 85% equity and if the case study farmer increases borrowings to change the farm business (in the ways described earlier) then debt servicing obligations will increase (Table 17).

Table 17. Total Capital investment, equity percentage, debt and annual debt servicing obligations for each of the Northern Victoria case study farm alternate farm futures (Terms of the amortised loan: 15 years and 7% interest)

	Total capital investment	Equity %	Debt	Annual debt servicing obligations
Base	12,539,416	85%	1,880,912	206,514
Adapt	15,498,856	69%	4,804,645	527,524
Grow	22,990,856	50%	11,495,428	1,262,136
TCN	20,127,781	56%	8,856,224	972,366
Adapt + methane inhibitor	15,498,856	69%	4,804,645	527,524
Adapt + animal efficiency	15,498,856	69%	4,804,645	527,524
Adapt + new feedbase	15,498,856	69%	4,804,645	527,524
Adapt + all three new technologies	15,498,856	69%	4,804,645	527,524

The more debt servicing obligations increase, the greater the risk of negative net cash flows (Figures 7-8) and thus the greater the total risk the business faces. In Figures 7 and 8, annual net cash flow with and without debt servicing is represented. As highlighted with the red arrows, there is a greater decline in the likelihood of annual net cash flow being positive for the Grow (without debt the likelihood of positive net cash flow is more than 90%, with debt the likelihood is less than 60%). This reiterates the importance of considering an investment from the economic and financial perspectives. Although the 'Grow' farm future is likely to add the most to wealth, it is also the option with the highest capital investment and could have the highest debt servicing obligations. In deciding which farm future is the 'best' for the case study farmers it also depends on their equity and their attitude to risk.

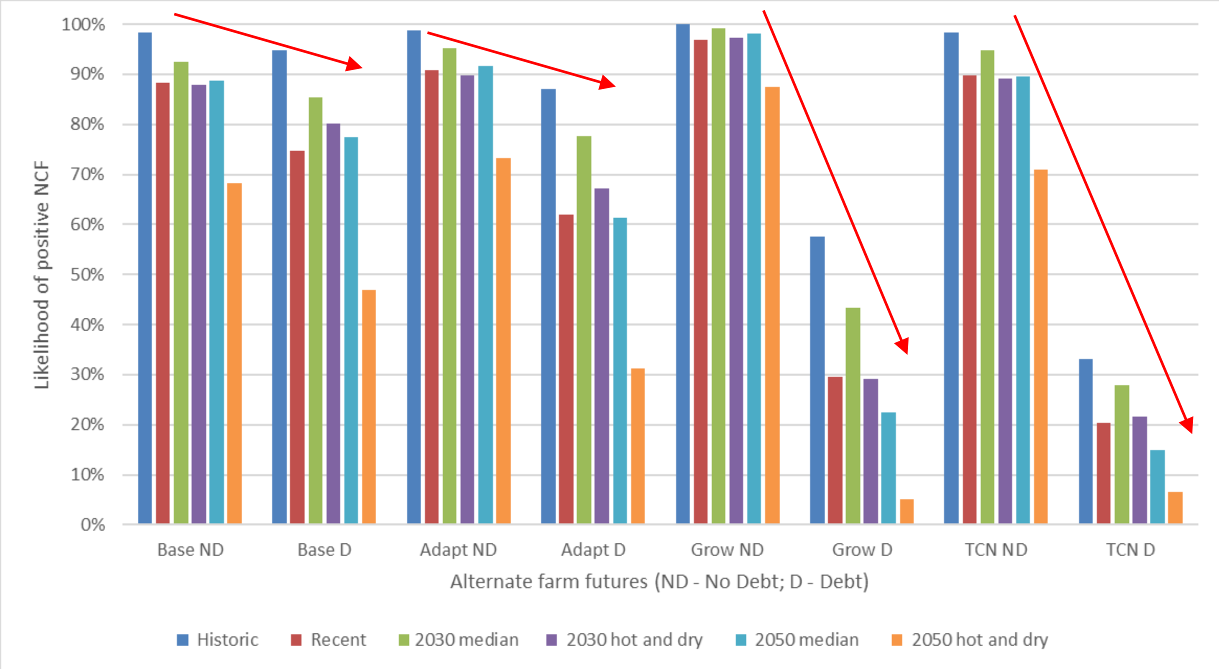


Figure 24. Likelihood of positive net cash flow for each of the alternate farm futures based on existing technology with and without debt. Each arrow highlights the reduced likelihood of positive net cash flows from borrowings.

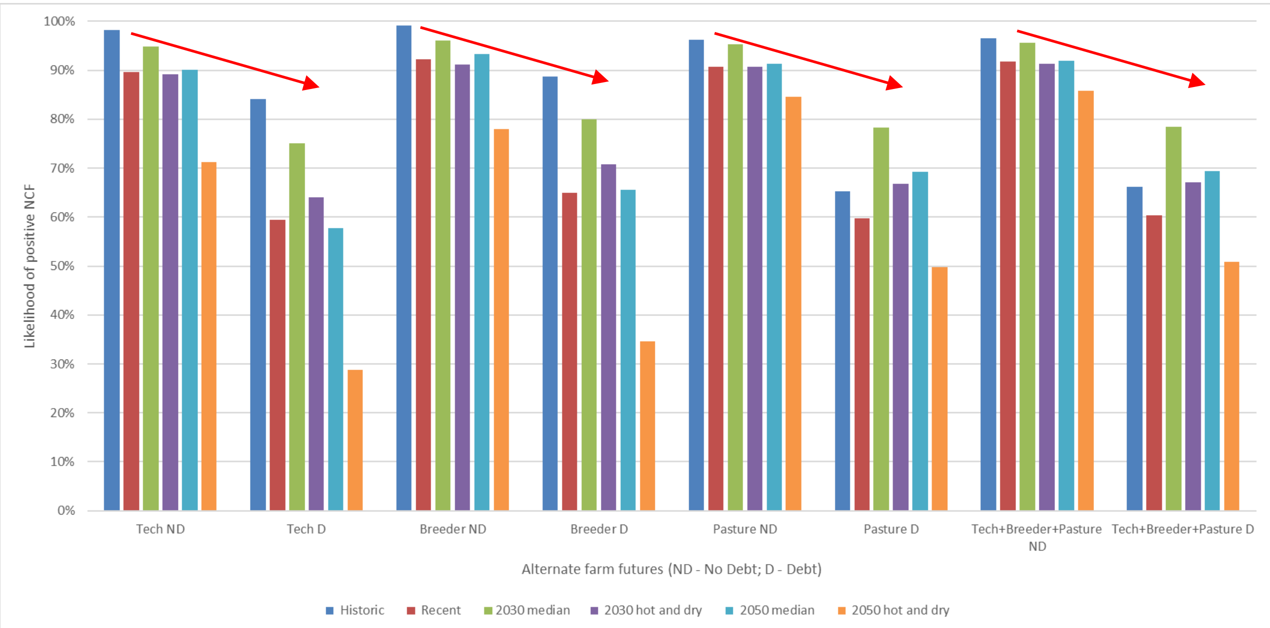


Figure 25. Likelihood of positive net cash flow for each of the alternate farm futures based on future possible technology with and without debt. Each arrow highlights the reduced likelihood of positive net cash flows from borrowings.

4.3 Northern New South Wales

4.3.1 Impacts of Future climates on pasture production

A summary of the temperature and rainfall for each of the scenarios is provided in Table 18. Comparing the Baseline and Recent scenarios, annual rainfall had declined by 7%, while temperatures had increased in summer and spring. The 2030 and 2050 projections reflect a continuation of the warmer trend, with increasing rainfall in autumn and declining rainfall in winter and spring. Atmospheric carbon dioxide concentrations were assumed to be 350 ppm for Baseline, 380 ppm for Recent, 450 ppm for 2030 scenarios and 530 ppm for 2050 scenarios.

Table 18. Long-term average rainfall (mm) and temperature (°C) statistics for the Baseline and Recent scenarios, together with rainfall (percentage) and maximum temperature (°C) changes relative to Baseline (1986-2005) for the future projections at Coolah.

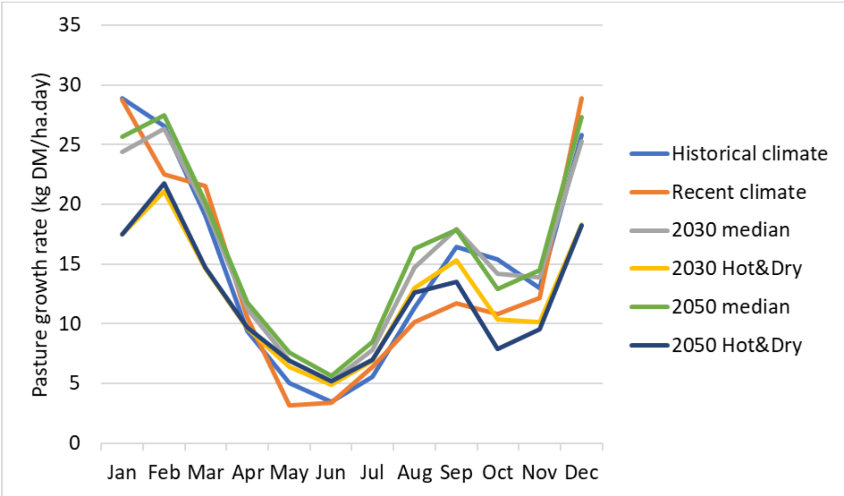
Season	Baseline	Recent	2030 Mid	2030 Hot&Dry	2050 Mid	2050 Hot&Dry
Rainfall						
Summer	218 (98-449)	197 (81-444)	-1%	-14%	+5%	-7%
Autumn	137 (30-410)	136 (41-342)	+14%	-3%	+14%	-2%
Winter	136 (45-322)	118 (37-347)	-4%	-11%	0%	-17%
Spring	161 (57-278)	152 (41-301)	-8%	-19%	-7%	-20%
Annual	651 (408-835)	603 (322-1052)	641 (302-1071)	561 (270-940)	661 (316-1113)	570 (272-974)
Average temperature						
Summer	30.7	31.1	+1.1	+1.6	+1.8	+2.3
Autumn	23.9	23.9	+0.6	+0.9	+1.3	+1.6
Winter	16.2	16.5	+0.4	+0.7	+1.0	+1.3
Spring	24.4	25.0	+0.9	+1.2	+1.7	+2.3

Impacts on pasture growth rates

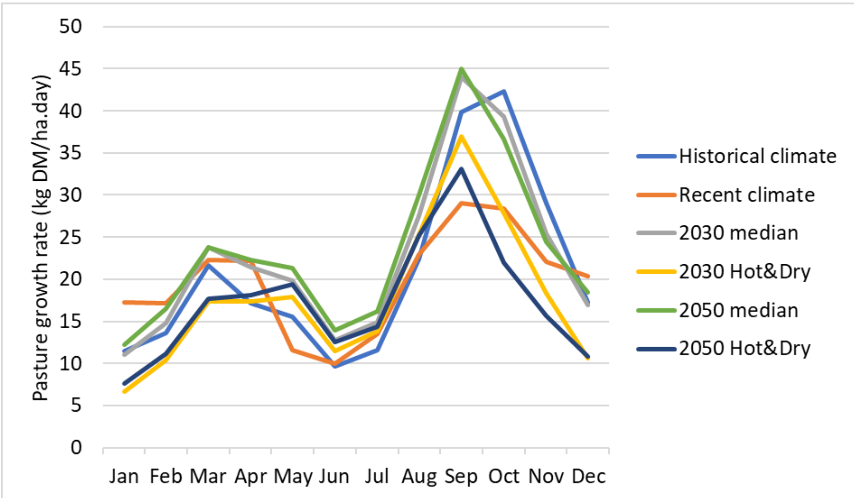
Pasture production for native C3/C4 grass pastures, Phalaris/lucerne pastures and Rhodes grass/subclover were simulated using the SGS Pasture model. The impact of climate scenarios on monthly pasture harvested (available for grazing) is shown in figure 17. In the baseline climate, the Rhodes/subclover had the highest annual pasture harvested (6.2 t DM/ha), followed by Phalaris/lucerne (5.6 t DM/ha) and native pasture (2.7 t DM/ha). In the median climate scenario for 2030 and 2050, all pasture types modelled increased production compared to the baseline climate, but the percentage increase was lowest for Phalaris/lucerne compared to the other pasture types that contained C4 species. In the 'hot and dry' climate scenarios, pasture harvested was predicted to decrease, but the native pasture was least affected (Figure 26).

The patterns of change are reflected in the farm-level estimates of pasture consumed, which show increasing pasture in 'median' climate scenarios (Figure 27), but lower pasture harvested and utilised in 'hot and dry' scenario (Figure 28).

(a) Native C3/C4 grass pasture



(b) Phalaris/lucerne pasture



(c) Rhodes grass/sub clover pasture

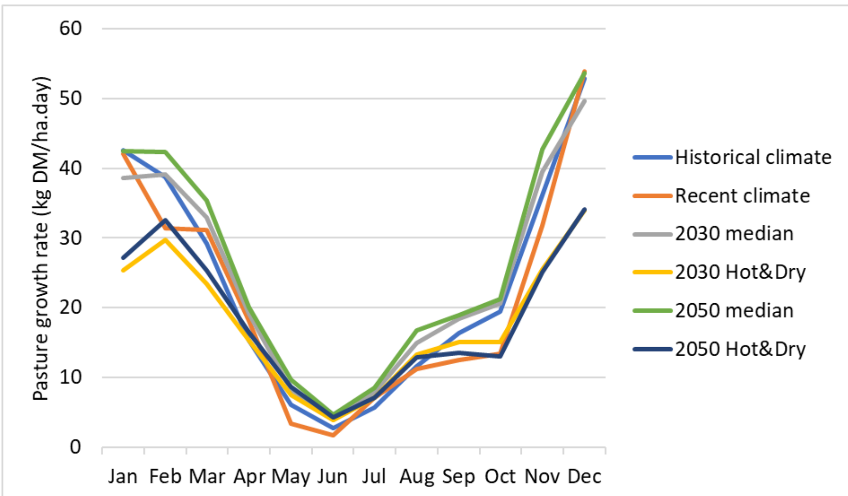


Figure 26. Simulated monthly average pasture growth rate (kg DM/ha.day) for (a) native C3/C4 grass pasture (b) Phalaris/lucerne pasture, and (c) Rhodes grass / sub clover pastures in the six different climate scenarios in the NSW case study.

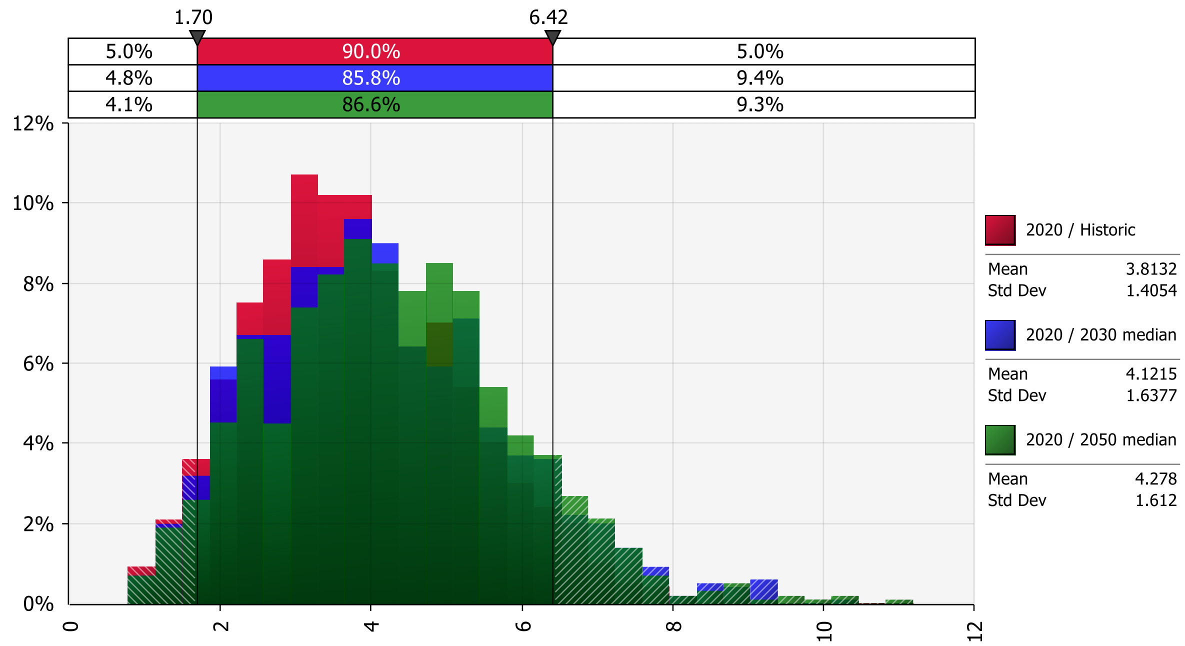


Figure 27. Annual pasture consumed (t DM/ha) for the historic, 2030 and 2050 climate for the 2020 farm system in the NSW case study.

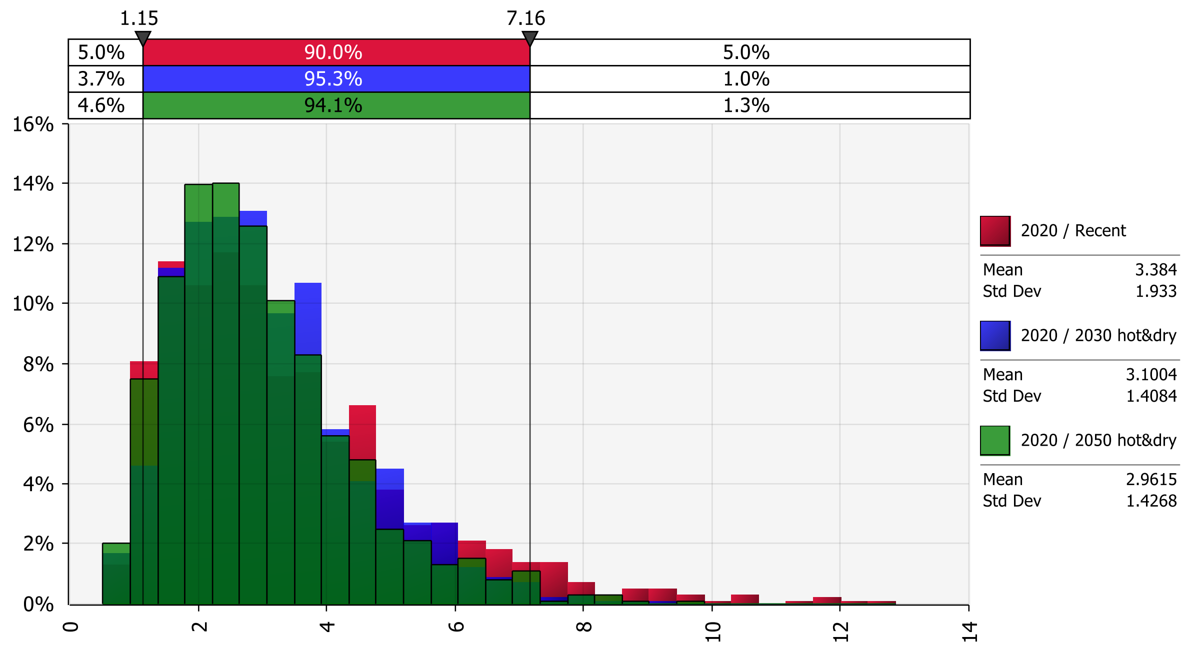


Figure 28. Annual pasture consumed (t DM/ha) for recent climate, 2030hot&dry climate and 2050 hot&dry climate with 2020 farm system in the NSW case study.

4.3.2 Future farm options

The future farm options for the NSW case study are summarised in Table 19.

Table 19. Summary of the Base farm, Adapt, Towards Carbon Neutral and Diversify and Grow options for the northern NSW case study.

Option	Changes implemented
Base Farm (capital value = \$9.6 million)	The case study farm business is located at Cassilis, NSW. The effective area is 1821 hectares consisting of 320 ha of arable land containing a mixture of sown pastures and forage crops and 1500 ha of native pastures containing a mixture of Danthonia and Microlaena. A 'steady state' livestock enterprise has been defined with the case study farmer, and is briefly described as: • Sheep: self-replacing Merino ewe flock with some cross-breds. 3500 mature ewes (August lambing, 126% lamb weaning overall). All wether lambs sold at 35kg or 50kg. Merino ewe lambs kept to 18 months age are classed and joined (replacement ewes) or sold. Cattle: Self-replacing herd. 350 mixed age cows joined. Calving in August. 90% weaning. Surplus heifers and steers sold at ≈9 months age.
Adapt (capital value = \$9.9 million)	1. Increase feed supply • Increase arable area of farm from 320 to 500 ha, and sow arable area to tropical grass/sub clover mix. Area of native pasture reduced (Replacing native pastures with tropical grasses on 180ha). • As part of the pasture improvement, it is assumed that paddock sizes were reduced. 2. Increase animal performance • increase in lamb survival of twins/triplets from 80 to 90% 3. Reduce greenhouse gas emissions. • Plant 10 ha of trees on unproductive areas of the farm in areas that will provide shelter to ewes bearing multiples (co-benefit).
Towards Carbon Neutral (capital value = \$11.8 million)	All changes in the 'Adapt' option plus: • Reduce livestock emissions: o Feed steers 2 kg grain/day with 3-NOP (30% methane reduction) for 60 days to finish earlier. (NB. lower methane reduction assumed as supplement is only part of the diet) • Plant 20% of non-arable area to trees (264 ha). Tree carbon sequestration rate = 10 t CO_2e/ha per year (averaged over 25 years) recognising difficulty of establishing trees on this property.
Diversify and grow (capital value = \$17.6 million)	All changes in the 'Adapt' option plus: • Purchase 1000 ha in Binnaway (to expand and provide spatial diversification); valued at \$6,000/ha (improved pasture), it will carry 9 DSE/ha.

4.3.3 Greenhouse gas emissions

The Base farm's total arm GHG emissions was 3,564 t CO_2e annually. Enteric methane was the major source of emissions (Figure 20). The emissions intensities for sheep meat, wool and beef production were 5.8, 21.7 and 12.0 t CO_2e per tonne of product sold, respectively. The GHG emissions for the

Adapt option were similar to the Base farm, with total emissions of 3,631 t CO_2e per year, and emissions intensities for sheep meat, wool, and beef production were 5.9, 22.1 and 12.0 t CO_2e per tonne of product sold respectively.

The whole farm GHG emissions and emissions intensity of sheep meat, wool and beef for all the farm northern NSW options and climate scenarios are displayed in Tables 20 and 21, respectively. The major emission source on the Base farm was enteric methane (83%) (Figure 17). As with the Victorian case studies, the climate scenarios had a moderate effect on whole farm GHG emissions and emissions intensity due to changes in the pasture utilised.

The base farm in the Recent climate had 3514 t CO2e and very low emissions intensity for sheep meat and wool production due to high lambing rates, rapid lamb growth rates and high wool cut. The Adapt option had a small increase in total GHG emissions but lower emissions intensity due to an increase in products sold with higher animal performance. In the TCN option, the GHG emissions were reduced, but not to zero, with 20% of non-arable land planted to trees. Total emissions increased in the 'Diversify and Grow' option due to the expanded livestock business.

Of the transformational research options, the methane inhibitor had the largest impact on total GHG emissions and emissions intensity reducing emissions to 32% of the Adapt farm. Increased animal efficiency (achieved through lower mature size) reduced the emissions intensity of production but did not reduce total GHG because the excess pasture was consumed by agisted livestock.

Table 20. Net total farm GHG emissions (t CO_2e/year) for the NSW case study in the eight farm options and six climate scenarios.

Option	Historic	Recent	2030 median	2030 Hot and Dry	2050 median	2050 Hot and Dry
Base farm	3514	3514	3753	3639	3850	3717
Adapt	3464	3524	3748	3553	3872	3604
TCN	789	771	714	1019	714	1064
Grow and Diversify	5498	5357	5643	5659	6084	5690
Adapt with High ME pasture	3820	3891	4122	3452	4264	3506
Adapt with Animal Efficiency	3559	3618	3844	3320	3968	3372
Adapt with methane inhibitor	1054	1114	1338	1141	1462	1194
Adapt with Pasture, Animal and Inhibitor	1616	1695	1917	940	2060	1095

Table 21. GHG emissions intensity of sheep meat, greasy wool, and beef production (t CO_2e/t product sold) for the NSW case study in the eight farm options and six climate scenarios.

Option	Product	Historic	Recent	2030 median	2030 Hot and Dry	2050 median	2050 Hot and Dry
Base farm	Sheep meat	5.2	5.3	5.2	5.5	5.2	5.6
	Wool	19.2	19.9	19.2	20.5	19.2	20.8
	Beef	11.7	12.4	11.7	12.9	11.7	13.3
Adapt	Sheep meat	5.1	5.1	5.1	5.3	5.1	5.4
	Wool	18.9	18.9	18.9	19.9	18.9	20.1
	Beef	11.4	11.4	11.4	12.3	11.4	12.5
TCN	Sheep meat	1.3	1.3	1.2	1.6	1.2	1.7
	Wool	4.9	4.8	4.5	5.9	4.5	6.1
	Beef	2.3	2.2	2.0	3.3	2.0	3.5
Adapt with High ME pasture	Sheep meat	5.1	5.1	5.1	5.2	5.1	5.3
	Wool	18.9	18.9	18.9	19.4	18.9	19.7
	Beef	11.4	11.4	11.4	11.8	11.4	12.1
Adapt with Animal Efficiency	Sheep meat	4.8	4.8	4.8	5.0	4.8	5.1
	Wool	18.0	18.0	18.0	18.5	18.0	18.8
	Beef	11.0	11.0	11.0	11.5	11.0	11.7
Adapt with methane inhibitor	Sheep meat	1.4	1.4	1.4	1.6	1.4	1.7
	Wool	5.2	5.2	5.2	6.1	5.2	6.4
	Beef	3.3	3.3	3.3	4.2	3.3	4.4
Adapt with ALL three	Sheep meat	1.3	1.3	1.3	1.3	1.3	1.3
	Wool	4.9	4.9	4.9	4.9	4.9	4.9
	Beef	3.2	3.2	3.2	3.2	3.2	3.2

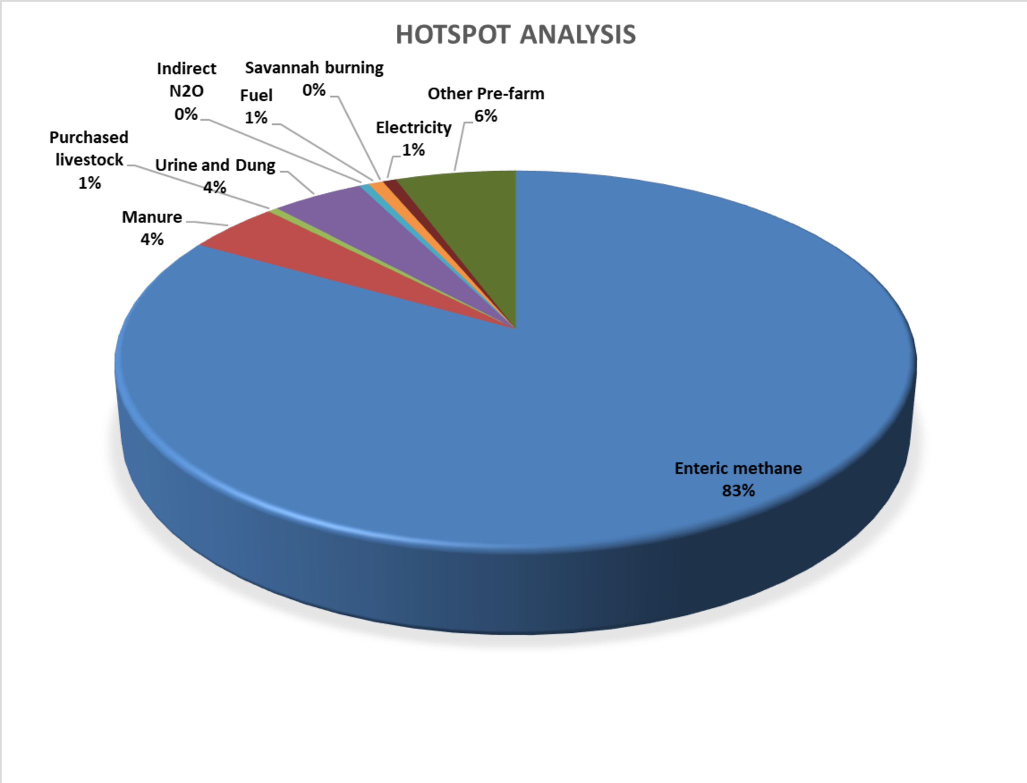


Figure 29. Percentage contribution of different sources to total farm GHG emissions of the Base farm in the northern NSW case study in the recent climate scenario.

4.3.4 Economic performance

The likely economic performance of the Base Northern NSW farm depends on how the climate changes. The Base farm is likely to add, on average, $4.2m to wealth over the next 20 years (after allowing for the 7% p.a. nominal cost of the capital tied up in the farm could earn in its next best use) if the next 20 years reflects the climate experienced over 1986 to 2005 ('Historic' climate). If the 'Recent' climate continues over the next 20 years then it is likely that the base farm will add, on average, $1.7m to wealth (a decline of 59% relative to if the Historic climate occurs). Interestingly, if the climate over the next 20 years is best represented by the modelled 2030 or 2050 median scenarios then the farm business could be more profitable than they are today (on average likely to add $4.9m or $5.2m to wealth over 20 years, respectively), because pasture growth is likely to increase in Northern NSW under these climate scenarios. However, if the modelled hotter and drier climate is more likely to occur then the Base Northern NSW property is likely to be less profitable than they are today (in the absence of adaptation) (Figure 30).

If the Northern NSW farm was run in the other alternate ways defined in Table 19, it is generally likely these could be more profitable than the Base farm, the only exception are the alternate futures that reduce greenhouse gas emissions in the absence of a price on carbon (Figure 31 – note for brevity only the distributions of NPV of each alternate farm future for the 2030 median climate change scenario is presented to demonstrate which alternate future is stochastically dominant). In Figure 32 and 33 the average addition to wealth of each alternate farm future for each climate is presented.

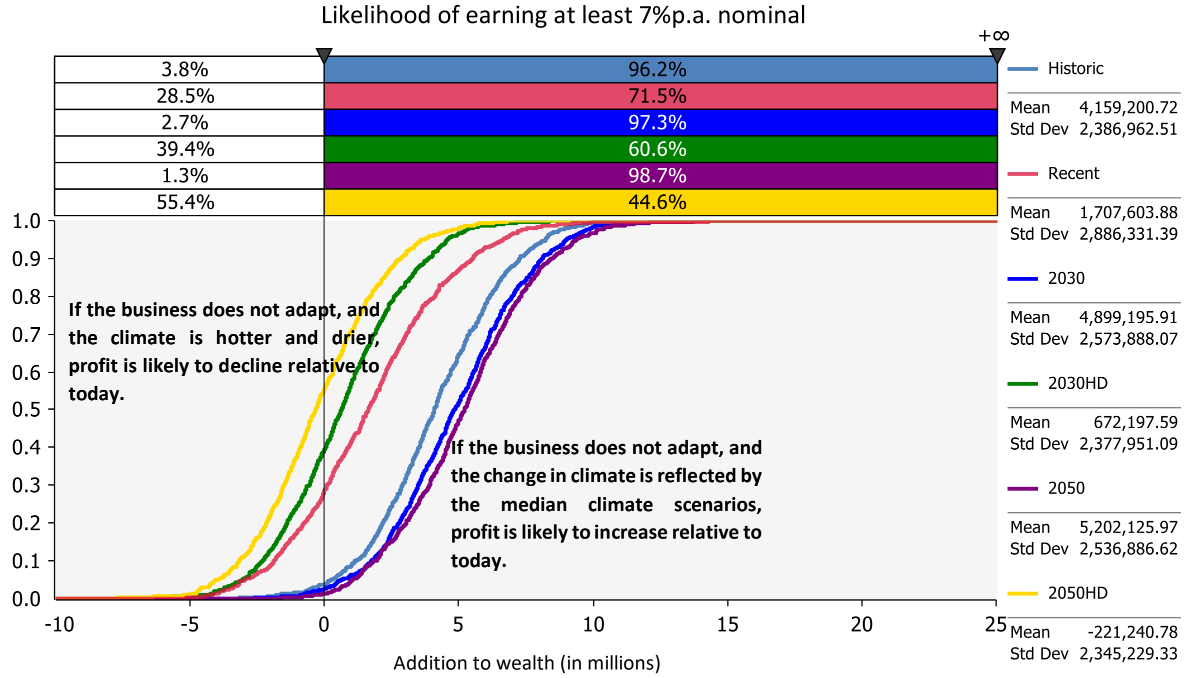


Figure 30. Likely addition to wealth (Net Present Value at 7% p.a. nominal discount rate) for the base farm under 6 different climate scenarios without a price on GHG emissions

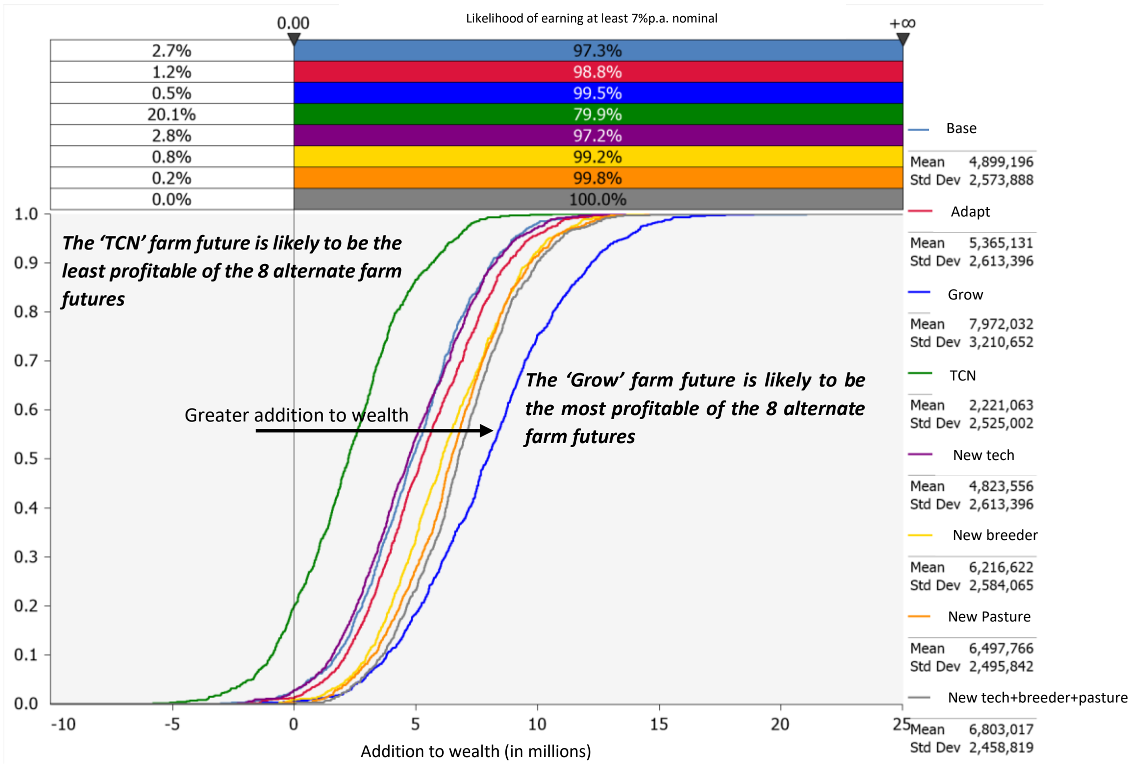


Figure 31. Likely addition to wealth over 20 years from running this farm as defined under each of the alternate futures under a 2030 median climate change scenario, without a price on GHG emissions, after allowing for the 7% p.a. nominal cost of the capital tied up in the farm could earn in its next best use. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

The Adapt alternate future is likely to add more to wealth than the Base alternate future under all the climate scenarios (Figure 31). For example, it is likely that the Adapt farm future will add on average $4.1 million to wealth over the 20 years in the Recent climate compared to $1.7 million for the Base farm with similar levels of inter-annual variability. Further, there is a greater chance of earning at least 7% p.a. nominal for the Adapt farm future in any of the climate scenarios (Table 22). As shown with the East Gippsland findings, the results from the Northern NSW farm also demonstrate that adapting to the climate by pasture improvements based on suitable species and increasing animal production are key to meeting the challenge of warmer and drier climates.

The 'Diversify and Grow' option is likely to add the most to wealth of all the alternative farm futures investigated (Figure 10). In all climate scenarios, the 'Diversify and Grow' farm future is likely to be more profitable than other investments in the economy, earning a 7% p.a. nominal return (Table 22)

The TCN alternate future is likely to add the least to wealth and has the lowest chance of earning 7% p.a. nominal (Figure 31 and Table 22). This highlights that there is a cost to the case study farm business to reduce emissions (mean NPV was approximately $3 million lower for all the options relative to the Adapt option).

If the transformational technologies that have been hypothesised in this study existed and had the characteristics described, then they are likely to increase the case study farmers wealth relative to a world without these technologies (the 'Adapt' scenario only, Figure 33). The only exception is the methane inhibitor as it added a cost to the farm business without a corresponding benefit (when a cost on emissions was not imposed) and thus reduced the likely addition to wealth compared to the Adapt option. A new pasture species that has an additional 1 MJ ME/kg DM and all the other attributes of the existing species is likely to add the most to wealth. Similarly, if the Adapt farm future also has a smaller breeder that has all other attributes of current breeders on farm, then it is likely that this will add more to wealth than Adapt with existing technology.

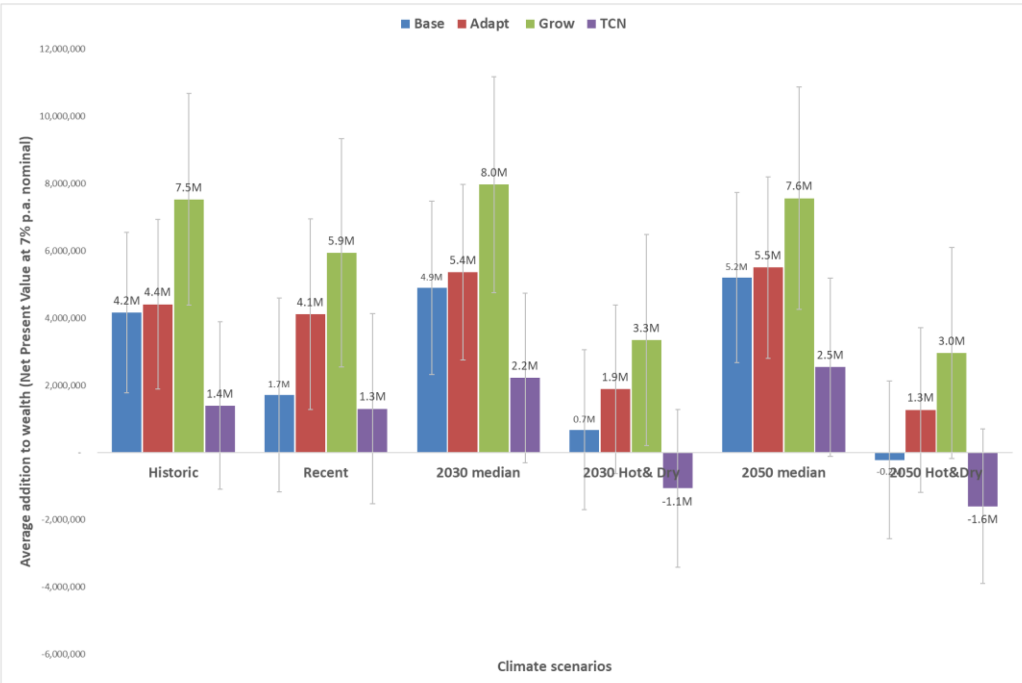


Figure 32. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the Northern NSW case study farm, run in four different ways using current technology under six climate scenarios without a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future.

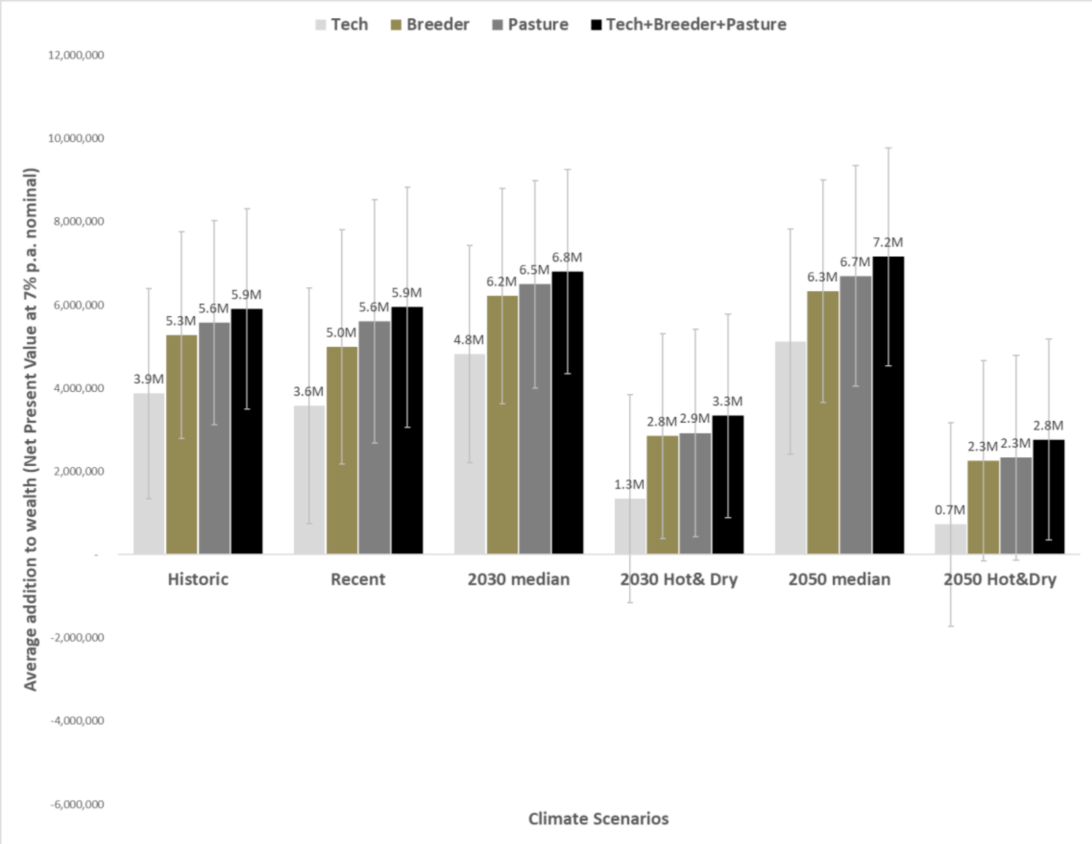


Figure 33. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the Northern NSW case study farm, run in four different ways using hypothetical future technology under six climate scenarios without a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase; and 'Newtech+breeder+pasture' is all three combined).

Table 22. Likelihood of earning at least 7% p.a. nominal for each of the alternate futures explored, without a price on GHG emissions.

	Historic	Recent	2030 median	2030 Hot& Dry	2050 median	2050 Hot&Dry
Base	96%	71%	97%	61%	99%	45%
Adapt	96%	93%	99%	78%	99%	69%
Grow	99%	96%	99%	86%	99%	84%
TCN	70%	66%	80%	32%	84%	25%
Adapt + methane inhibitor	93%	90%	97%	69%	98%	60%
Adapt + animal efficiency	99%	97%	99%	89%	99%	83%
Adapt + new feedbase	99%	98%	100%	88%	99%	83%
Adapt + all three new technologies	100%	98%	100%	91%	100%	86%

A price on greenhouse gas emissions will add an extra cost to the farm business and is likely to reduce overall farm profit (Figure 34 and 35).

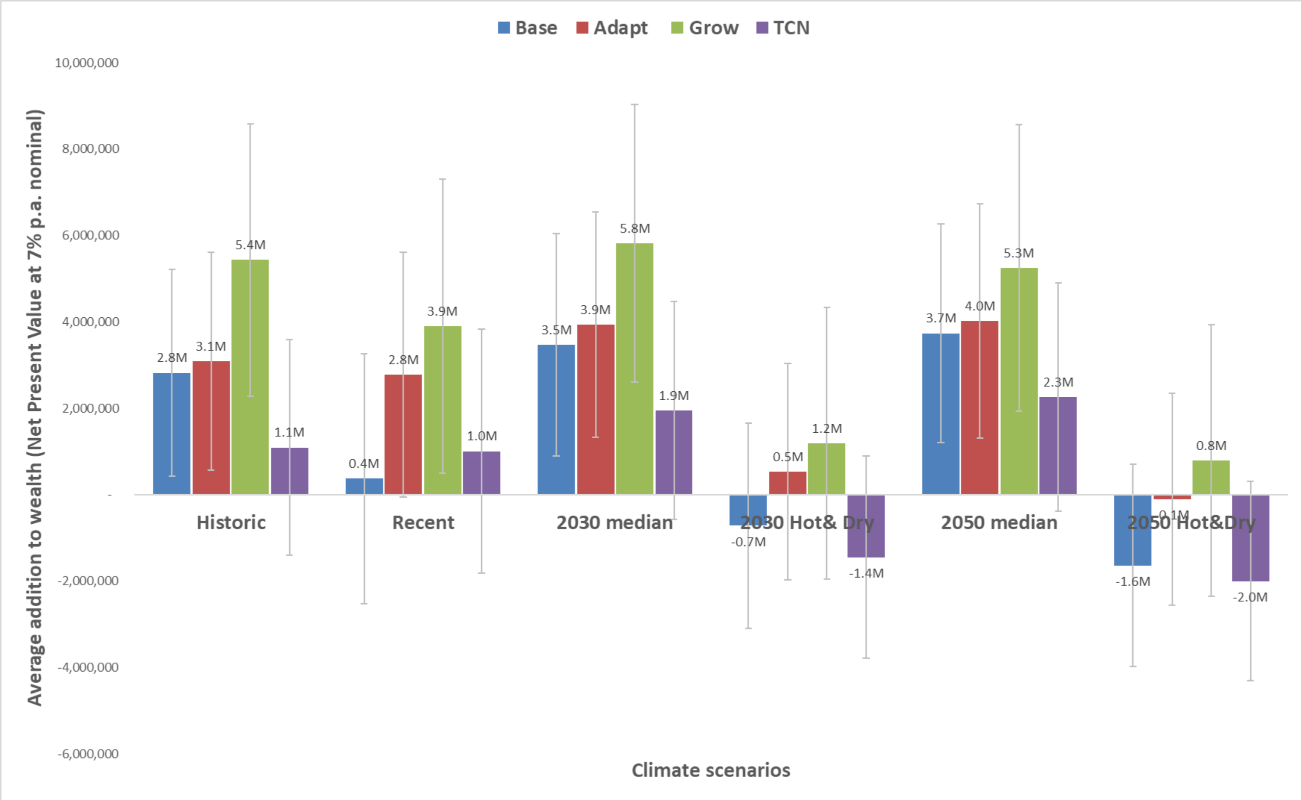


Figure 34. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the Northern NSW case study farm, run in four different ways using current technology under six climate scenarios with a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future.

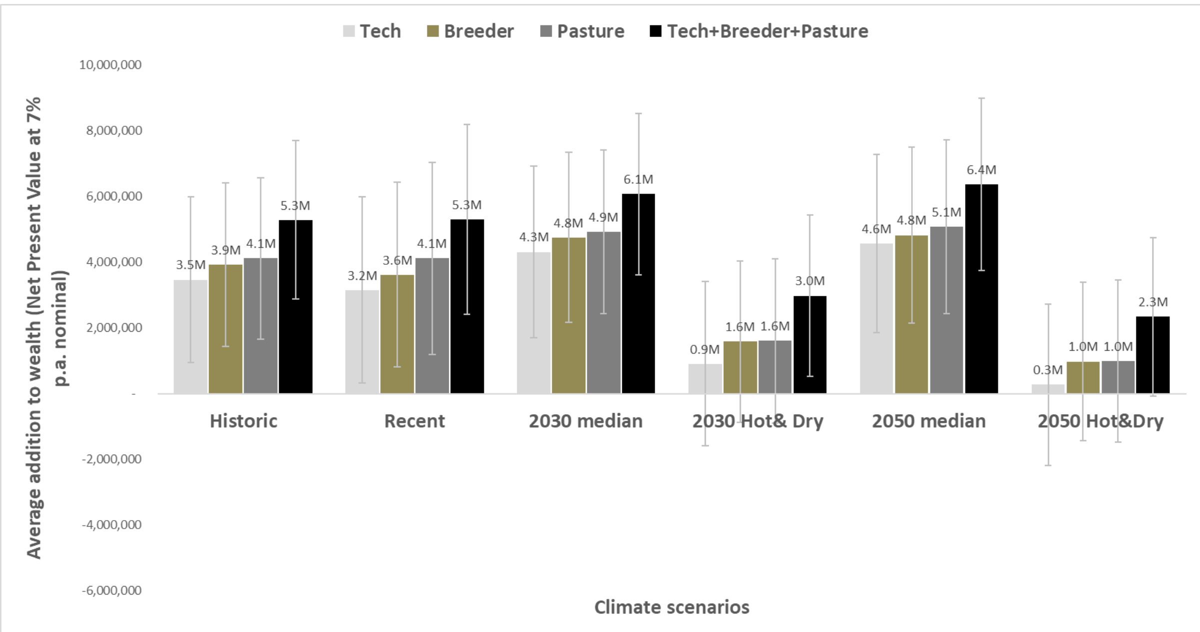


Figure 35. Average addition to wealth (Net Present Value at 7% p.a. nominal) for the Northern NSW case study farm, run in four different ways using hypothetical future technology under six climate scenarios with a price on GHG emissions. Note the error bars reflect the standard deviation for each alternate farm future. (Note for legend: 'New tech' = methane inhibitor; 'New breeder' = animal efficiency; 'New pasture' = feedbase'; and 'Newtech+breeder+pasture' is all three combined).

Financial results Northern NSW

If the Base farm has 85% equity and if the case study farmer increases borrowings to change the farm business (in the ways described earlier) then debt servicing obligations will increase (Table 23).

Table 23. Total Capital investment, equity percentage, debt and annual debt servicing obligations for each of the Northern NSW case study farm alternate farm futures (Terms of the amortised loan: 15 years and 7% interest)

	Total capital investment	Equity %	Debt	Annual debt servicing obligations
Base	9,550,149	85%	1,432,522	157,283
Adapt	9,939,769	82%	1,818,978	199,714
Grow	17,629,769	50%	8,814,884	967,827
TCN	11,815,687	69%	3,662,863	402,163
Adapt + methane inhibitor	9,939,769	82%	1,818,978	199,714
Adapt + animal efficiency	9,939,769	82%	1,818,978	199,714
Adapt + new feedbase	9,939,769	82%	1,818,978	199,714
Adapt + all three new technologies	9,939,769	82%	1,818,978	199,714

The more debt servicing obligations increase, the greater the risk of negative net cash flows (and thus the greater the total risk the business faces. In Figure 36-37, annual net cash flow with and without debt servicing is represented. As highlighted with the red arrows, there is a greater decline in the likelihood of annual net cash flow being positive for the Grow (without debt the likelihood of positive net cash flow is 90%, with debt the likelihood is 60% or less depending on the likely climate). This reiterates the importance of considering an investment from the economic and financial perspectives. Although the 'Grow' farm future is likely to add the most to wealth, it is also the option with the highest capital investment and could have the highest debt servicing obligations. In deciding which farm future is the 'best' for the case study farmers it also depends on their equity and their attitude to risk.

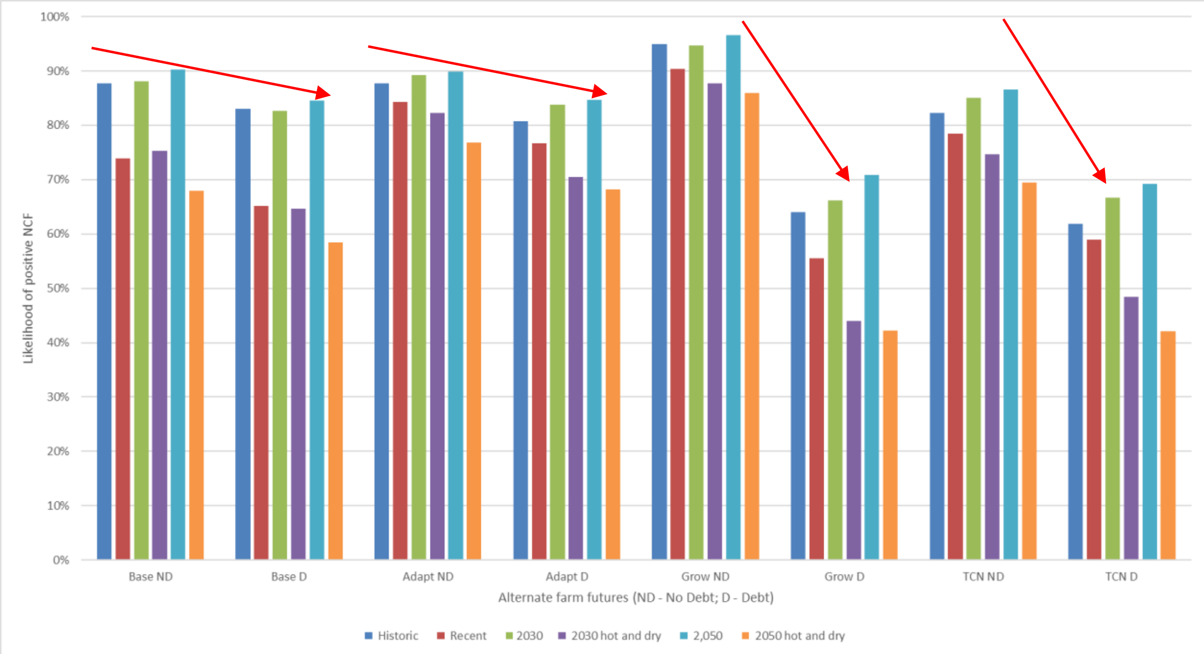


Figure 36. The likelihood of annual net cash flow being positive without debt and with debt for the four alternate ways the Northern NSW farm could be run over the next 20 years using current technology. (The no debt scenario shows the business risk, the debt scenario shows the total risk as it includes the added financial risk from debt servicing.)

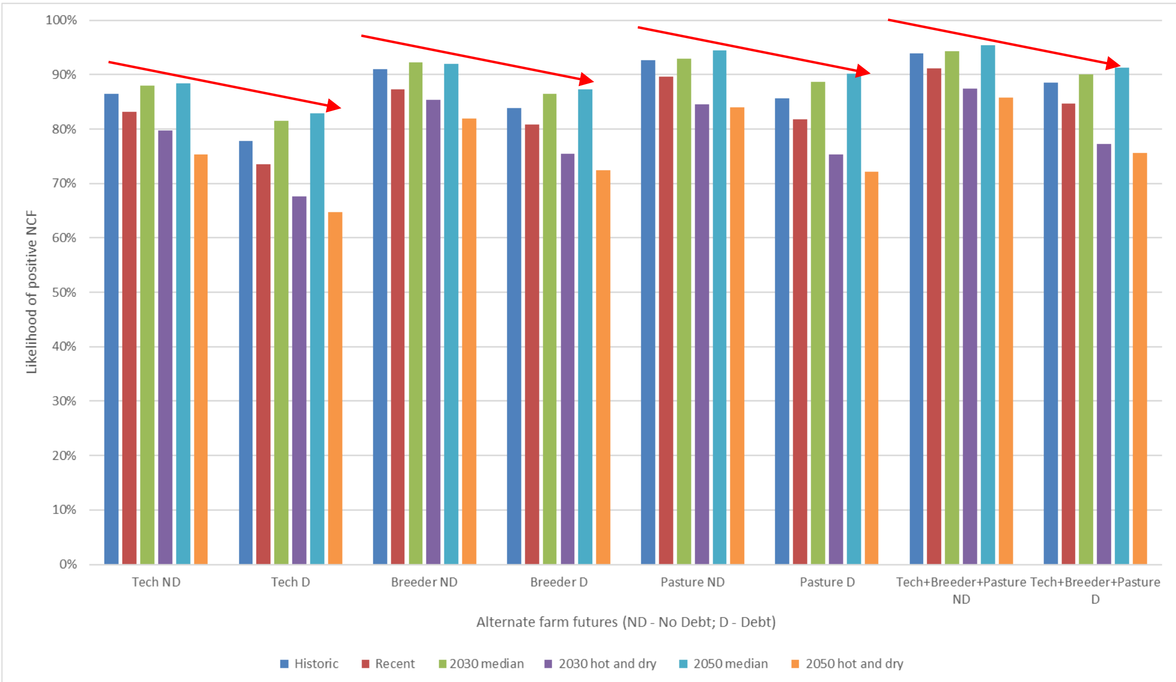


Figure 37. The likelihood of annual net cash flow being positive without debt and with debt for the four alternate ways the Northern NSW farm could be run over the next 20 years using hypothetical future technology. (The no debt scenario shows the business risk, the debt scenario shows the total risk as it includes the added financial risk from debt servicing.)

4.4 Central Queensland case study

The Central Queensland case study is fully described in Appendix 8.3 and a summary of results is provided here.

4.4.1 Impact of Future Climate on pasture and animal production

Summer and spring growth will be lower in 2030 compared to historical due to a reduction in seasonal rainfall (Figure 38). Autumn and winter growth will be higher in 2030 compared to historical owing to higher temperatures not limiting growth, causing a longer growing season. The higher growth in winter for 2030 will not be sufficient to outweigh the lower growth in summer and spring – shown by lower annual growth in 2030 compared to historical (Table 24).

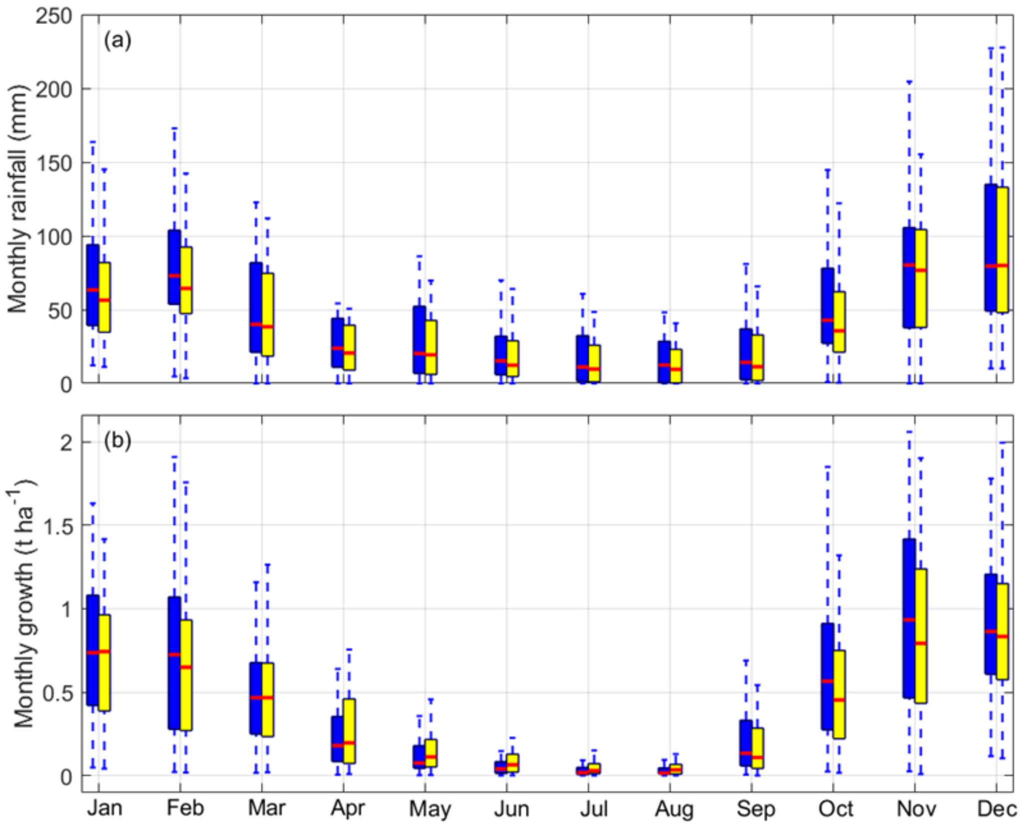


Figure 38. Monthly differences in rainfall (a) and pasture growth (b) between the historical (blue) and 2030 (yellow) climates.

Historical climate has higher animal numbers than 2030 climate in all initial land conditions, indicating that 2030 climate will reduce the sustainable herd size. Better initial land conditions allow greater and more stable animal numbers (Figure 39). Even with good land condition, animal number is more vulnerable to drought in a 2030 climate (Fig 39a). For example, during the extreme droughts such as the 1995-98 drought, animal number is stable in the historical climate when land condition is good but reduced notably in the 2030 climate.

Table 24. Animal number of the beef enterprise for the historical and 2030 climates at three initial land conditions, for instance, good, moderate and poor. The land condition can change from 0 (best) to 11 (poorest). The initial grass basal area (GBA) was set at 3% in the three cases.

Initial land condition	Initial Land condition index	Average animal number		Standard deviation	
		Historical climate	2030 climate	Historical climate	2030 climate
Good	1	3229	3248	623	617
Moderate	6	3194	3212	617	629
Poor	10	3190	3007	613	672

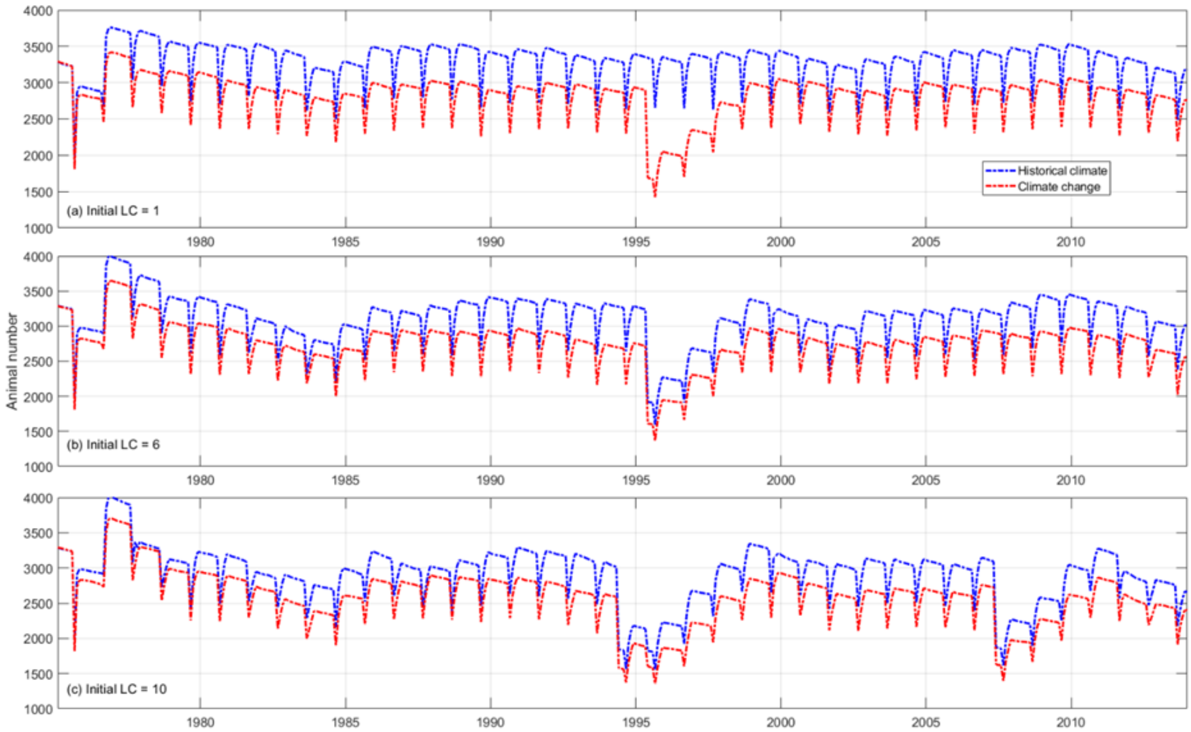


Figure 39. Total animal numbers in herds for the historical climate and 2030 climate at three initial land conditions (LCs) i.e. good (1; top), moderate (6; middle) and poor (10; bottom). The initial GBA was set at 3% in the three cases.

The 2030 climate had slightly higher annual liveweight gain of steers than that in the historical climate for G, M, P initial land conditions owing to better winter pasture growth (Table 25). The 2030 climate has higher liveweight gain of steers in winter than that in the historical climate for G, M and P initial land conditions (Table 26). Meanwhile, lightweight gains of steers in other seasons are equivalent in historical and 2030 climate, indicating that the annual pasture growth reduction in a 2030 climate will not influence the development of steers. Better winter pasture growth thus not only directly improve the weight gain in winter but also has positive carry over effects on animal weight gains in the other seasons.

Table 25. Annual weight gains of the steers (males up to 24 months) for the historical climate and 2030 climate at three initial land conditions i.e. good, moderate and poor. The initial GBA was set at 3% in the three cases.

Initial land condition	Initial Land condition index	Average annual weight gain (kg)	
		Historical climate	Climate change
Good	1	197	201
Moderate	6	184	191
Poor	10	172	183

Table 26. Seasonal weight gains of the steers (males up to 24 months) for the historical climate and 2030 climate at three initial land conditions i.e. good, moderate and poor. The initial GBA was set at 3% in the three cases.

Initial land condition	Initial land condition index	Seasonal average weight gain (kg)							
		Historical climate				2030 climate			
		Aut.	Win.	Spr.	Sum.	Aut.	Win.	Spr.	Sum.
Good	1	65	33	40	60	65	37	41	59
Moderate	6	62	30	34	58	62	36	36	58
Poor	10	59	27	30	57	61	34	32	57

4.4.2 Greenhouse gas emissions

Monthly emissions were similar between historical and 2030 climate for G, M, P initial land conditions (Table 27).

Table 27. Monthly emissions of the beef enterprise in the historical climate and 2030 climate at three initial land conditions i.e. good, moderate and poor. The initial GBA was set at 3% in all three cases.

Initial land condition	Initial land condition index	Monthly average (tCO_2e)	
		Historical climate	2030 climate
Good	1	10.90	10.99
Moderate	6	10.74	10.83
Poor	10	10.63	10.09

4.4.3 Economic performance

Climate 2030 average annual profit was lower ($100-130K per year) than the historical climate for G&M initial land conditions (Table 28). Historical climate average annual profit was relatively similar to the 2030 climate for P initial land condition.

Table 28. The average annual profit of the beef enterprise in historical and 2030 climate at three initial land conditions, for instance, good, moderate and poor. The land condition can change from 0 (best) to 11 (poorest). The initial grass basal area (GBA) was set at 3% in all three cases.

Initial land condition	Initial land condition index	Average annual profit of the beef enterprise (AUDk)	
		Historical climate	Climate change
Good	1	931	801
Moderate	6	740	631
Poor	10	581	577

4.4.4 Adaptation

In terms of profit (Figure 40), improved pasture by sowing legume crops shows the best performance – average annual profit is greater ($305k per year) than that of the baseline historical climate. Improved rumen function is an option that can maintain the current baseline profit level. Improved conception to achieve a better weaning rate and improved growth rate can also mitigate the profit reduction due to climate change. Improved pasture can also allow an increase in the sustainable herd size i.e. without deteriorating land condition in long term (Fig. 41a) while other 3 adaptation options show reductions in sustainable herd size. This results in a similar pattern of the costs of production (Figure 41b). Improved pasture and rumen functions are the two options that can improve the economic efficiency of the available resources represented in gross margin per AE (Figure 41c) and gross margin per ha (Figure 42a). Improved pasture and rumen functions can also improve and maintain, respectively, the annual enterprise beef production (Fig. 41d). The four options show similar or slightly higher levels of average emission intensity compared to that under the baseline historical climate (Figure 41e). Improved pasture, growth rate and rumen function can achieve better monthly live weight gains in the 2030 climate than that of the baseline enterprise in the historical climate (Figure 42b). It should be noted that, without adaptation, the enterprise can still maintain or improve the average live weight gain (compared to that of the historical period) owing to better pasture growth in winter.

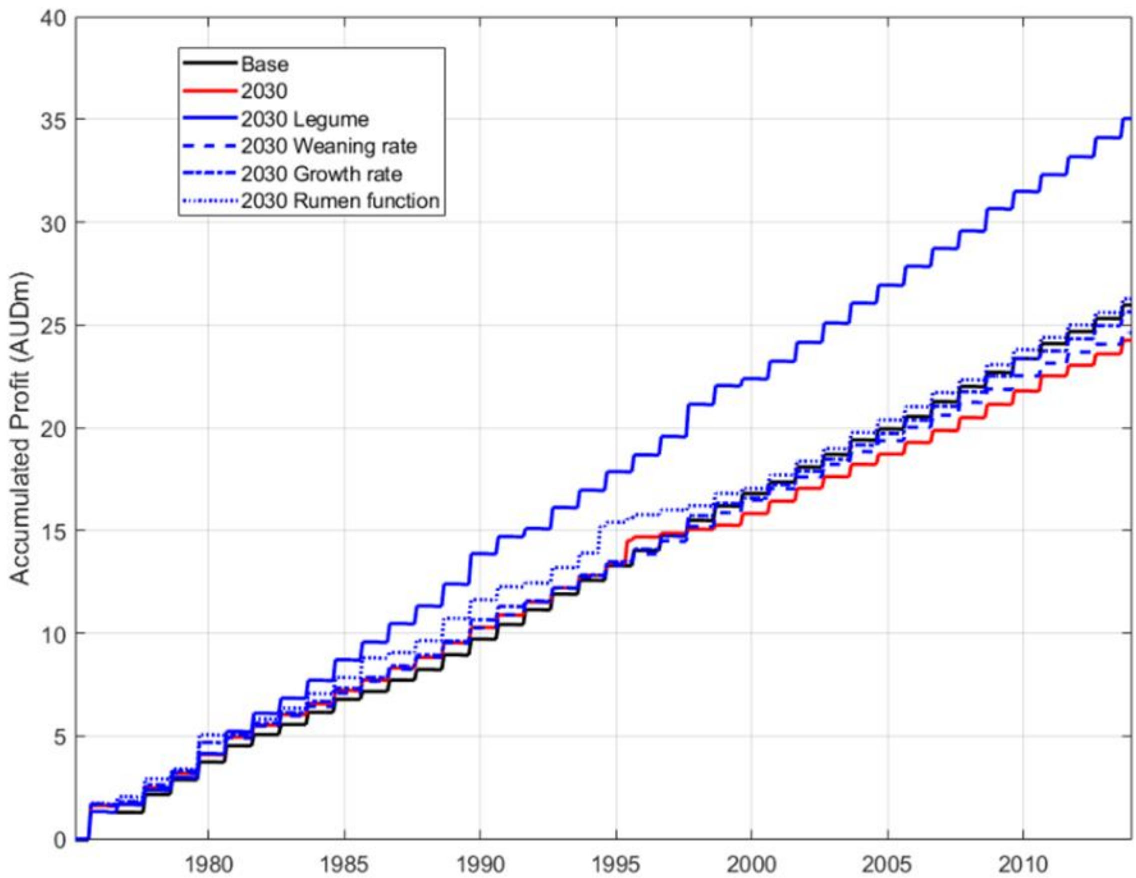


Figure 40. Accumulated profits in the historical and 2030 climates, and in the four adaptation options. The initial land condition was kept at moderate in all these simulations.

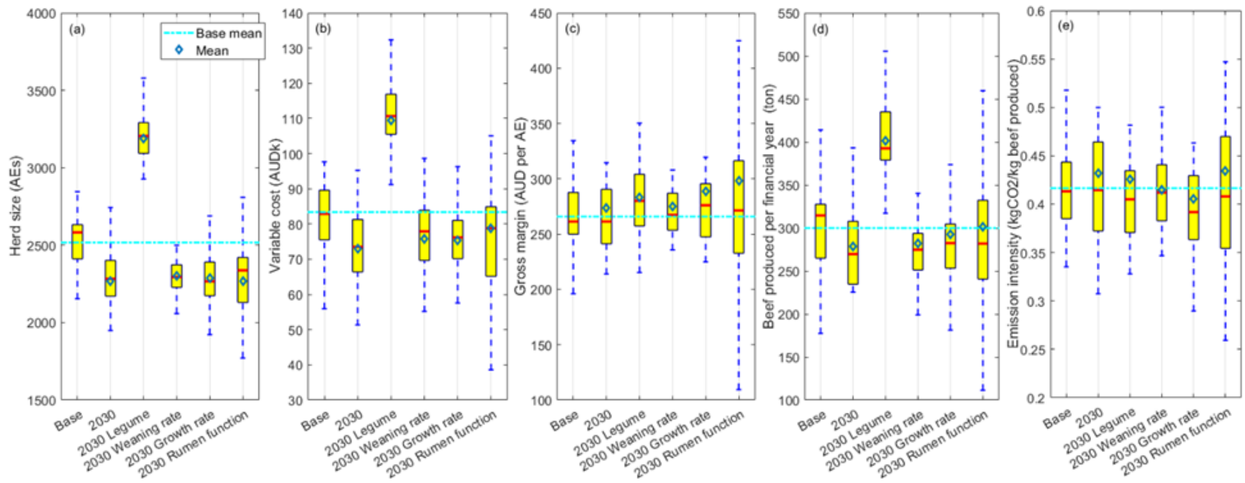


Figure 41. Combined results of five performance indicators (herd size, variable cost, gross margin per AE, beef produced per financial year and emission intensity) in the historical and 2030 climates, and in the four adaptation options.

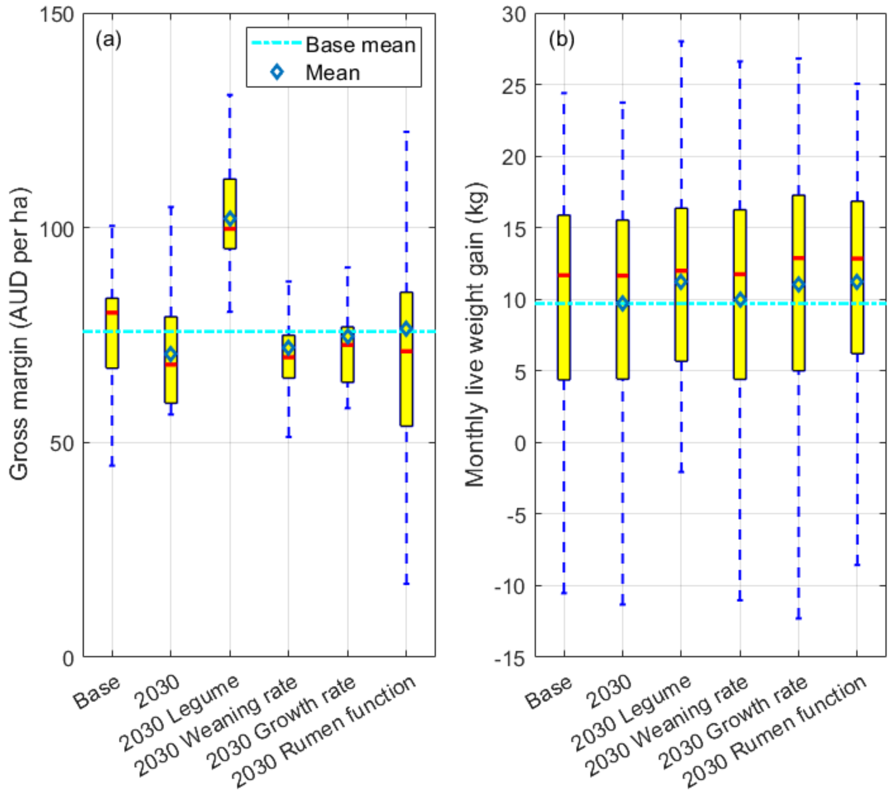


Figure 42. Combined results of gross margin per ha and monthly live weight gain (kg/head) of one year age group (12-24 months) in the historical and 2030 climates, and in the four adaptation options.

4.5 Human and social capacities and capabilities required to manage the modelled options

(This includes strategies to assess industry readiness to respond and plan for adaptation and mitigation as well as engage producers and farm advisors in building capacity for adaptation and transformation).

This report presents the social research findings from the Northern Victoria, East Gippsland and Northern NSW reference groups. The social research was designed to add value to the farm system modelling by providing insights into what needs to be considered for implementing the Nexus adaptation pathways in terms of human and social capabilities and capacities and to identify options to build adaptive and transformative capacity in the red meat industry to respond to climate-related changes. The social research was guided by the milestone requirements that were linked to a set of key social research questions (Table 29).

Table 29. List of final milestone requirements linked to key social research questions.

Milestone requirements	Social research questions
Part A) Report on the human and social capacities (willingness/motivations) and capabilities (skills/knowledge) required to manage the modelled scenarios at farm and industry scale	1) What are the human and social capacities and capabilities required to put the adaptive pathways into practice at the farm and regional scale?
Part B) Report on the strategies to assess industry readiness to respond	2) What are the opportunities and challenges with implementing the adaptation pathways by the red meat industry?
Part C) Report on producer and farm advisor engagement for building capacity for adaptation and transformation.	3) What are the key elements of an enabling environment to support climate related adaptive and transformative decision making in red meat production?

Understanding the biophysical and economic dimensions of agricultural systems under a changing climate is important in building the knowledge base for adaptation and transformation in the Australian red meat sector. However, it is also critical to explore the human and social aspects of adaptation/transformation and what they mean for ‘how adaptation [and transformation] can be realized in practice’ (O’Brien and Hochachka, 2010: 91). For example, a key risk is that technologically feasible adaptation pathways remain largely conceptual and the desirability of and commitment to their implementation by scientists, policymakers and practitioners is unexplored or unknown. This is why it is critically important to engage directly in climate change adaptation research (CCAR) with producers and other industry professionals through their participation in projects, such as Nexus, and through gathering social data on the capabilities and capacities for adaptation and/or transformation in practice (Sietsma et al. 2021).

4.5.1 Industry readiness to respond

Based on the sentiments and self-assessment of adaptive capacity to implement the Nexus adaptation pathways, the Northern Victoria, East Gippsland, and Northern NSW reference groups are well prepared to undertake the ‘adapt’ pathway and less prepared to undertake the ‘towards carbon neutral pathway’. The reference groups are willing to ‘diversify and grow’ their livestock businesses to some extent, but external constraints limit the opportunities. The overall sentiment (general view of) each of the adaptation pathways were similar across all three reference groups based on the focus group activities and questionnaire responses. The overall sentiments (in terms of feasibility/desirability) are summarised in Table 30.

Table 30. Summary table of the overall sentiments of the reference groups towards the Nexus adaptation pathways

Pathway	Overall sentiment
Adapt	**Doable:** achievable management practices that make good business and production sense for the whole industry.
Diversify and Grow	**Desirable**: attractive pathway, but external factors can determine feasibility and will not be an option for whole industry.
Towards Carbon Neutral	**An inevitable challenge**: currently considered a mostly unworkable pathway whether it be viewed as an obligatory change, business cost or opportunity.
Transformational	**Potential for significant benefits:** general interest in applying technological innovations.

Please see Appendix 8.4 for a more detailed description of the sentiments of the reference groups towards the Nexus adaptation pathways.

All three Nexus reference groups indicated that they are already doing some, if not all, the activities included in the 'adapt' pathway (for example, shifting calving and lambing times to match with pasture availability, pasture improvements and trading livestock) which demonstrates that reference group members currently have the skills and capabilities to adapt and to continue along this pathway. There is high motivation to implement the 'adapt' pathway since it was viewed as making good business and production management sense based on practical tactical activities. In contrast, there was a strong indication that there is less capacity for reference groups and the advisers' client base to implement the 'towards carbon neutral pathway' particularly in relation to human, social and physical capitals. The general sentiment is that it is too early to invest and implement such a pathway because of the multiple uncertainties involved (technical, financial and social). The political dimension of operating their business as a carbon neutral enterprise has led some reference group members to become sceptical about the legitimacy of changing their production system in this way.

The contrast in industry preparedness (i.e., producers' capacity and interest) between the 'adapt' and 'towards carbon neutral' pathways suggest there is an existing capacity to take short-term actions that incorporate quick wins and less capacity or readiness to invest in long term (strategic) activities with longer lead times for any potential 'wins' (that cannot be guaranteed at this point). The 'diversify and grow' pathway would appear to be an additional or bonus course of action to take if you can resource it in terms of investing in additional land, have good access to an agricultural workforce and high cognitive and affective capacity. All three reference groups indicated a similar level of adaptive capacity to implement both the 'diversify and grow' and 'adapt' pathway, although drawing on financial capital would appear to be a greater limiting factor for diversifying and growing the livestock business.

Overall capacity to implement the Nexus adaptation pathways across the five sustainable livelihood capitals

The questionnaire results amplify the general sentiments about the different Nexus adaptation pathways. The general tendency was for Nexus reference groups to perceive that that they had more capacity to 'adapt' and 'diversity & grow', and less capacity to implement the 'towards carbon neutral' pathway.

The radar graphs presented below (Figures 43-46) represent the average rating of each sustainable livelihood capital (human, social, financial, physical, and natural) as an aggregated response for each reference group across the three Nexus adaptation pathways (adapt, diversify & grow and towards carbon neutral). The average ratings indicate reference group members' perception of their current capacity (i.e., their own if they are a producer, their client base if they are a livestock adviser) to implement the Nexus adaptation pathways. If the average rating is below the value of 3.0 (black dotted line), this indicates less capacity to adapt. If the average rating sits above the value of 3.0 (black dotted line), this indicates more capacity to adapt because it signals these capitals (or resources) are available and/or being used.

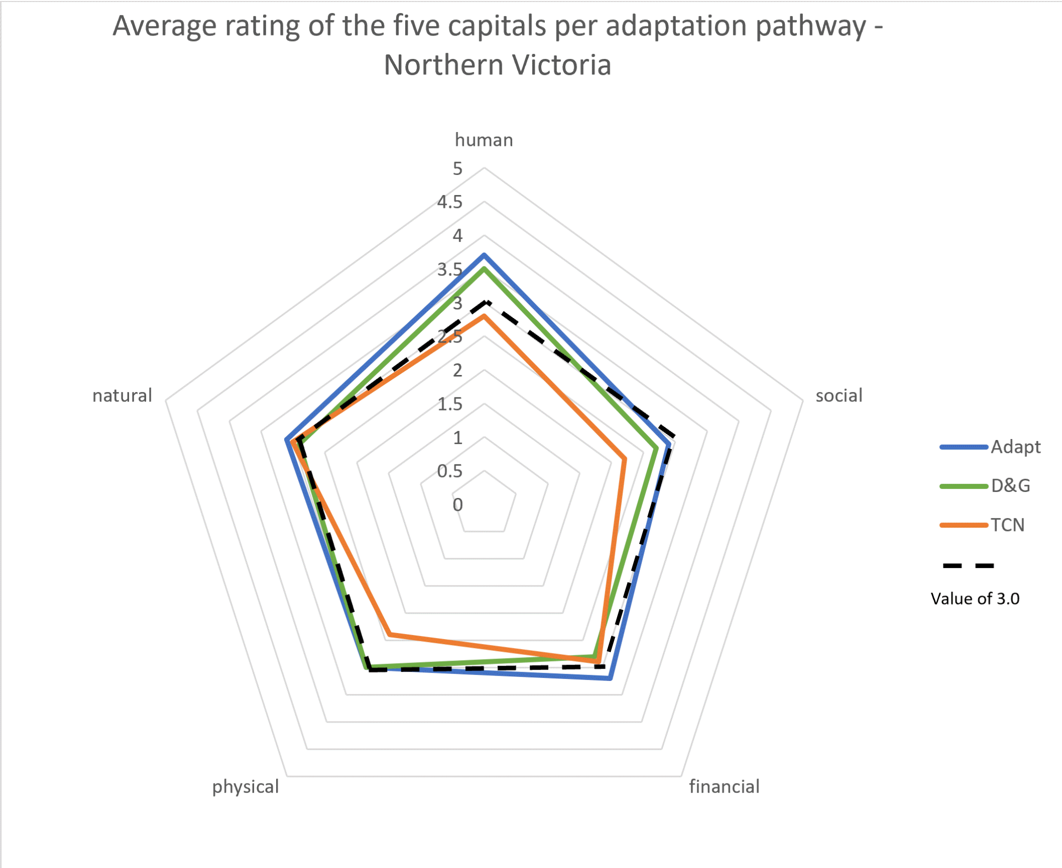


Figure 43. Average rating of the five capitals per adaptation pathway – Northern Victoria

The aggregated questionnaire responses from reference group members for the Northern Victoria case study indicates that they perceive themselves to have less capacity to implement the 'towards carbon neutral pathway', and more capacity to implement the 'adapt' and 'diversify & grow' pathways. The Northern Victoria reference group responses indicate a perception of more adaptive capacity when it comes to drawing on human capital and slightly less adaptive capacity when it comes to drawing on social and financial capitals particularly for diversifying and growing and transitioning toward carbon neutral production.

For a presentation of the distribution of responses (more capacity, neutral, less capacity) per questions across the three Nexus adaptation pathways, please see Appendix 8.4.

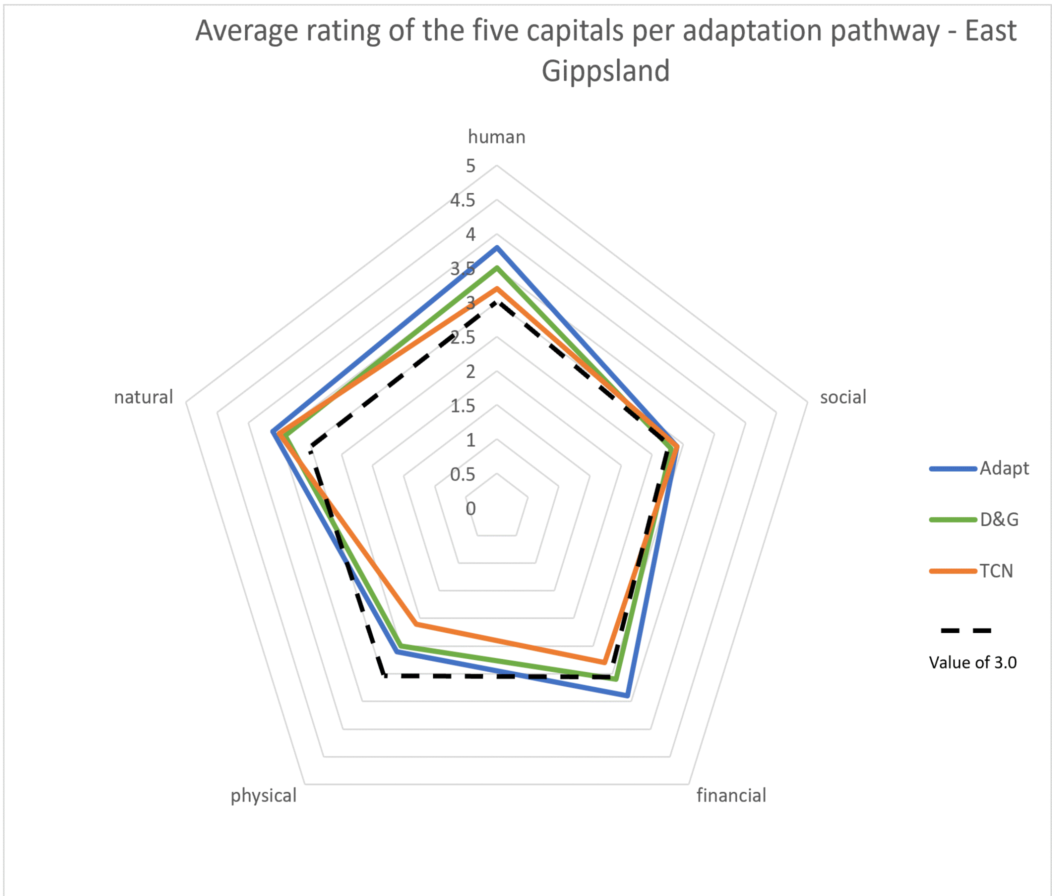


Figure 44. Average rating of the five capitals per adaptation pathway – East Gippsland

The aggregated questionnaire responses from the East Gippsland reference group indicates a general perception that there is more capacity to implement the 'adapt' and 'diversity and grow' pathways, and less capacity to implement the 'towards carbon neutral pathway'. However unlike the Northern Victorian reference group, the East Gippsland reference group indicated that there is some capacity to transition towards carbon neutral production when drawing on human and natural capitals. The East Gippsland reference group responses indicate a perception that while there is human and natural capitals to enable adaptation by implementing the Nexus pathways, there is less adaptive capacity when it comes to drawing on social, financial and physical capitals i.e. the unavailability or inaccessibility of social, financial and physical capitals constraint their adaptive capacity.

For a presentation of the distribution of responses (more capacity, neutral, less capacity) per questions across the three Nexus adaptation pathways, please see Appendix 8.4.

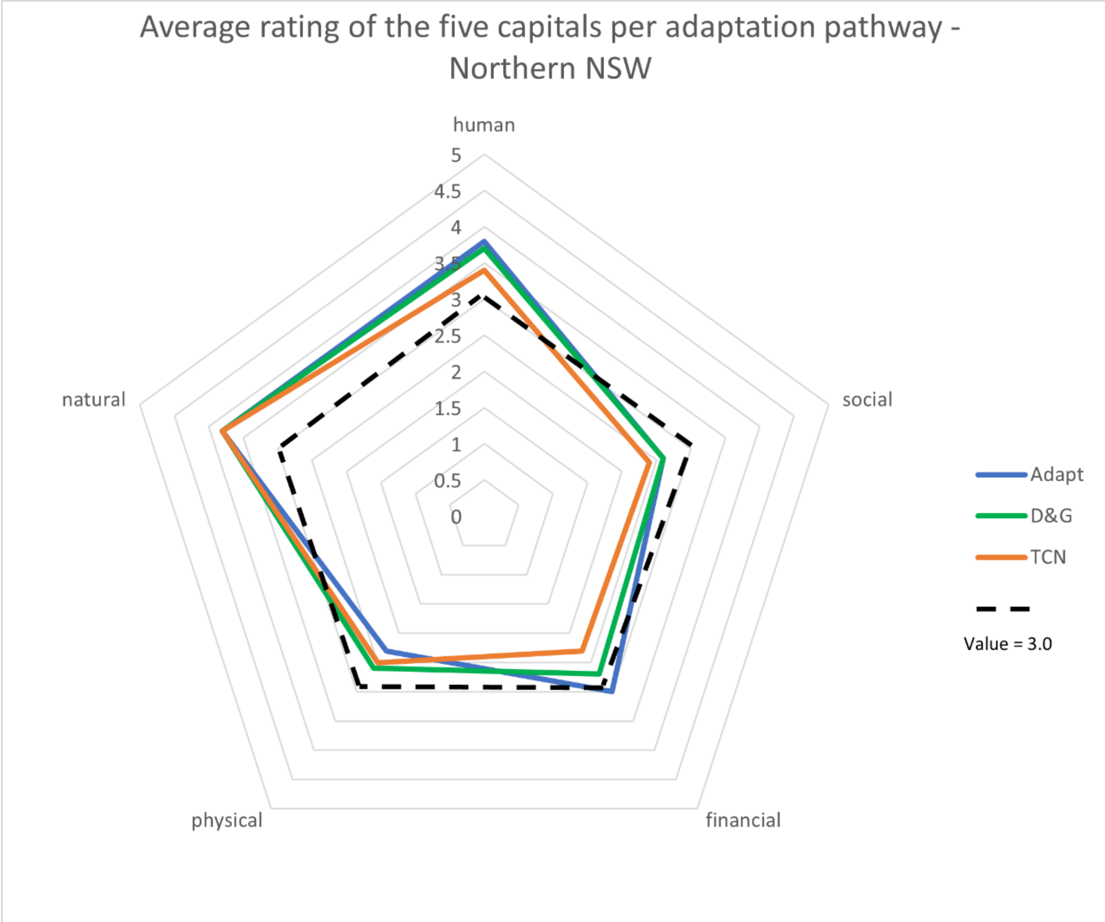


Figure 45. Average rating of the five capitals per adaptation pathway – Northern NSW

The aggregated questionnaire responses from the Northern NSW reference group indicates a similar perception to Northern Victoria and East Gippsland in that there is (somewhat) less capacity to implement the 'towards carbon neutral pathway', and more capacity to implement the 'adapt' and 'diversify & grow' pathways. However, like East Gippsland it is perceived that there is more capacity to implement all three adaptation pathways when drawing on human and natural capitals, and less capacity to implement all three adaptation pathways when needing to draw on social, financial, and physical capitals.

For a presentation of the distribution of responses (more capacity, neutral, less capacity) per questions across the three Nexus adaptation pathways, please see Appendix 8.4.

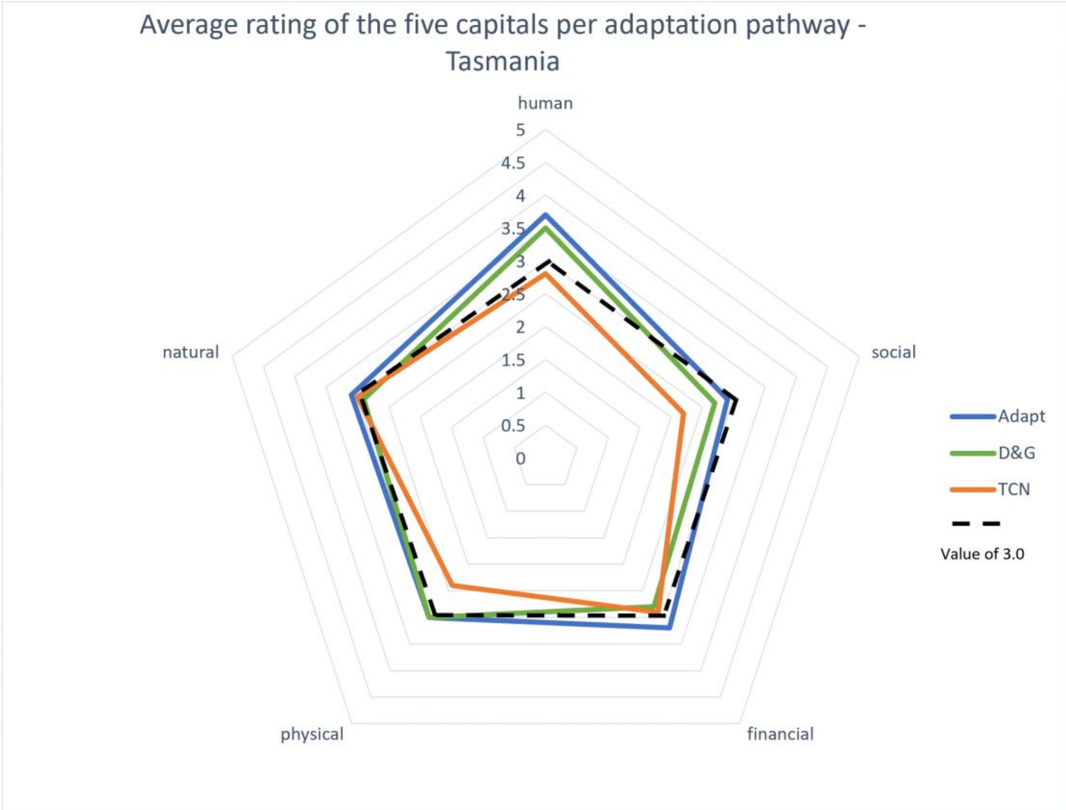


Figure 46. Average rating of the five capitals per adaptation pathway – Tasmania

The aggregated questionnaire responses from the Tasmanian reference group indicates that they perceived themselves to have less capacity to implement the 'towards carbon neutral pathway', and more capacity to implement the 'adapt' and 'diversify & grow' pathways. The Tasmanian reference group responses indicate a perception of having more adaptive capacity when it comes to drawing on human capital and slightly less adaptive capacity when it comes to drawing on social and financial capitals particularly for diversifying and growing and transitioning toward carbon neutral production.

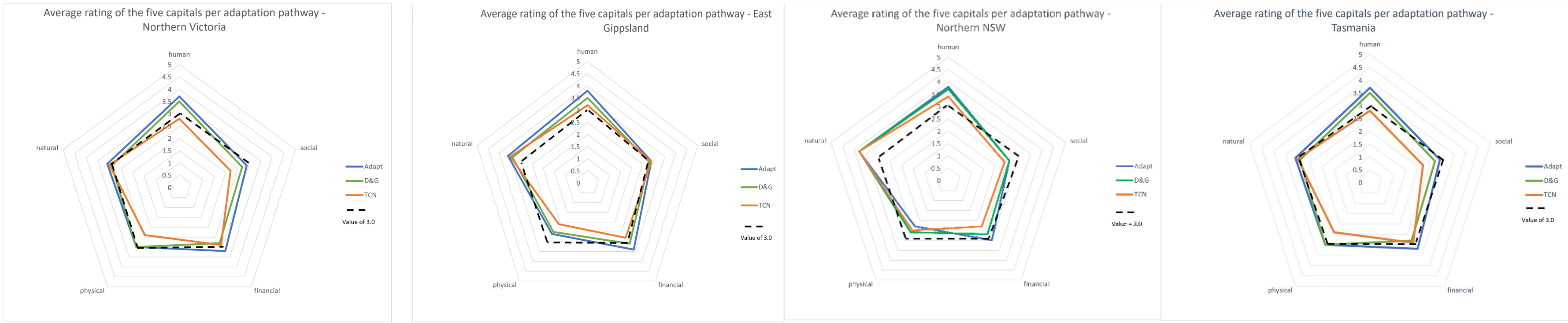


Figure 47. Average rating of the five capitals per adaptation pathway as a cross reference group comparison.

If the radar graphs are presented for the Northern Victoria, East Gippsland, Northern NSW and Tasmania reference groups as a cross reference group comparison (Figure 47), there is a general tendency for Nexus reference groups to perceive that that they had more capacity to 'adapt' and 'diversity & grow', and less capacity to implement the 'towards carbon neutral' pathway. However, East Gippsland and Northern NSW indicated that there was some capacity to transition towards carbon neutral production when it comes to drawing on human and natural capitals. Across the four reference groups, there was a general perception of having less capacity for adaptation regardless of the pathway when it comes to drawing on social, financial and physical capitals. Support for adaptation to regional climate change may therefore need to focus on investing in building and strengthening the social, financial and physical capitals (resources) to enhance the adaptive capacity of Nexus reference group producers.

The social research from the Nexus project indicates the importance of strengthening the physical, financial and social capital of livestock production regions for climate change adaptation and mitigation and suggests the following ways to strengthen the enabling environment for climate change resilience in the red meat sector:

Physical capital: greater efforts are needed to target regional investments in improving digital communications infrastructure so that producers can utilize software for monitoring farm system performance and accessing live on-farm data for strategic and tactical decision making. There may also be a need to revisit regional water catchment policy to clarify access and use of local water resources that is evidence based, as well as identifying new or reinforcing current opportunities for water harvesting and conservation that will support profitable and environmentally sustainable red meat production. Sometimes physical capital is about securing the foundation infrastructure for the livestock business (e.g. fencing, water storage, feed storage).

Financial capital: there is scope for the financial sector (financial institutions) to consider providing more flexible lending conditions to facilitate producer investment in strategic adaptation and mitigation activities; this could include providing more specific business risk management advice and options, as well as easier access credit when production conditions are good and more flexible loan conditions. Although the traditional banks and financial institutions are increasingly developing financial products that finance environmental and sustainable outcomes on rural properties, there are no equivalent financial products for those producers wanting to invest in climate change adaptation and mitigation. Financing institutions could consider adding climate change adaptation and mitigation criteria when assessing loan applications from producers.

Social capital: there is an ongoing need to continually improve extension and advisory services that are regionally relevant; this could include linking producers to already existing programs and activities for the 'adapt' pathway and developing specific services and workshops that focuses on 'diversifying and growing' livestock business based on an adapting farming system, as well as identifying a range of options for transitioning 'towards carbon neutral' production. Support for adaptation and mitigation of GHG emissions in the red meat sector is reliant on strengthening producer and advisor learning networks, and keeping discussions and lines of inquiries open between producers, advisers, researchers and regional stakeholders because adaptation and mitigation needs to take place in a rapidly evolving decision context.

Please note that the radar charts presented indicate the Nexus reference groups' average rating of each adaptive capacity statement. For a breakdown of the reference group members' responses to each rated statement for human and social capitals, please refer to Appendix 8.4.

Regardless of the how the reference groups assessed their own or their clients' current capacity to implement the Nexus adaptation pathways, when reference group members were asked to indicate the likelihood of considering or advising clients on each Nexus adaptation pathway, most members are likely to consider or provide advice on the 'adapt', 'towards carbon neutral' and 'transformational' pathways (Figure 48). These responses suggest that the Nexus reference groups generally had an interest in thinking about and reflecting on the modelled adaptation pathways as a point of possibility and interest.

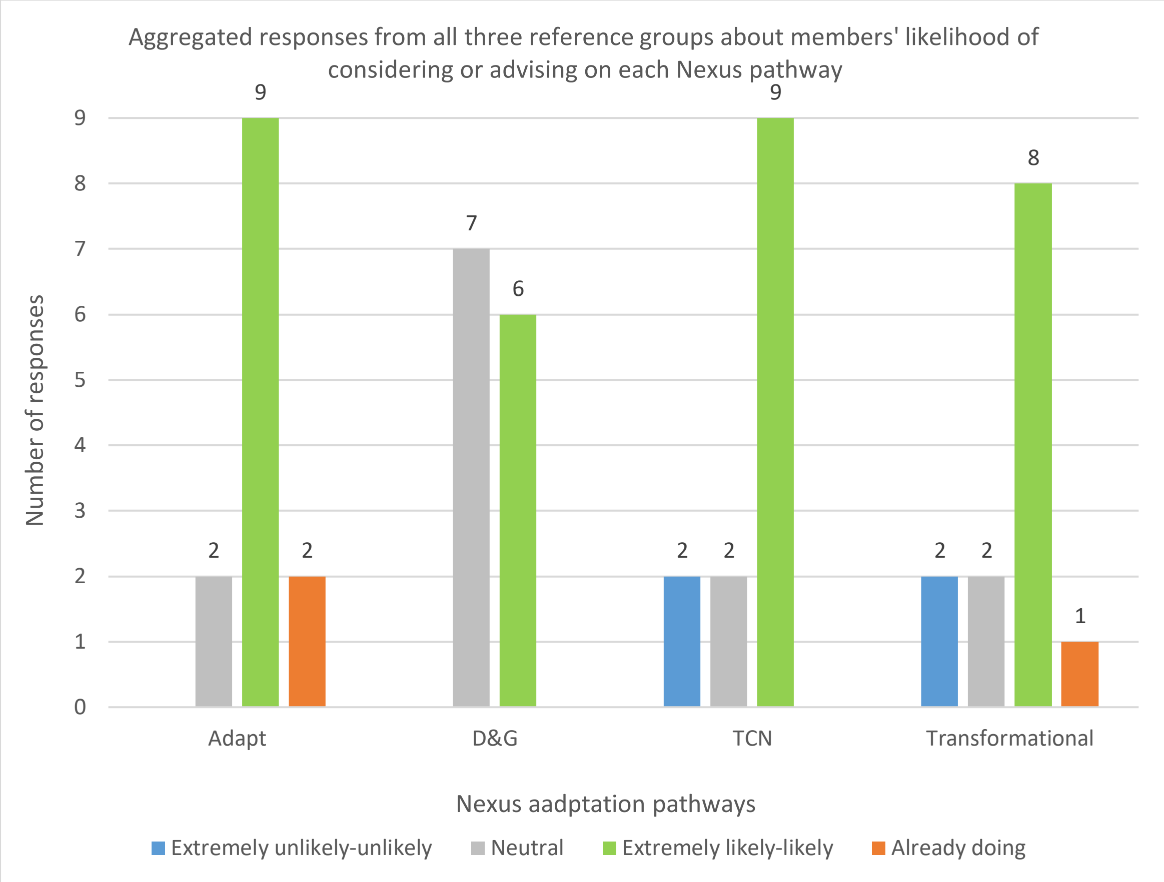


Figure 48. Aggregated responses from all three reference groups about members' likelihood of considering or advising on each Nexus pathway.

Capabilities required to implement the Nexus adaptation pathways

Implementing the different Nexus adaptation pathways are likely to draw on both generic and specific skillsets, knowledge and abilities. Therefore, having the capability to implement one pathway does not mean that a producer will have the skills and capabilities to implement other adaptation and mitigation pathways (Table 31). It is likely that red meat producers will require the development of both breadth and depth in capabilities for adaptation and mitigation, especially if a producer is committed to implementing all three adaptation pathways simultaneously as their own tailored course of action. Extension and advisory services will need to cater to the specific needs of each adaptation and mitigation pathway, as well as the ability to integrate skills across multiple pathways – if producers seek a multi-pathway approach to adapting their production system.

Table 31. List of differentiated skill and capabilities identified by the Nexus reference groups to implement the Nexus adaptation pathways

Pathway	**Skills and capabilities -** this table has added the findings from the producer interviews undertaken for the Southern Gulf Region case study also.
Adapt	Involves management skills and capacities that should be widely implemented across the industry and includes: - Being vigilant with record keeping so that you know your whole farm system comprehensively i.e., off the top of your head, you should know your critical numbers (herd size, costs, reproduction rates, feedbase budget, long-term carrying capacity) - upskilling in pasture and fodder management (sometimes strengths are in animal management, rather than feed production) - Willingness to adjust the system every year from real-time observations – let go of your plans! (But hard to know what is having an effect on what when there is such variability in the seasons e.g., shifting joining/calving dates) - seeing opportunities in situations as they emerge (e.g., opportunistic cattle trading), while at the same time, have a long-term view of your business - ability to scrutinize a high volume of different information to consider and then having the confidence to decide which information to value
Diversify & Grow	- Developing new skills in animal management if introducing a new livestock breed/species (beef, sheep, goats) - Capacity to identify additional labour needs and how to manage/integrate this into the current workforce arrangement - Capacity to invest in any additional infrastructure (irrigation, feed storage, fencing, machinery) - Developing new skills in managing/monitoring property for the provision of ecological services - Need high mental and physical capacities to diversify if it means introducing a new enterprise/new off-farm or non-agricultural income (this secondary enterprise or income needs to be something a producer is passionate about otherwise there is risk of it becoming a burden, not an asset)
Towards Carbon Neutral	- Currently the entry point to this pathway is confusing - “Unknown unknowns” - in terms of what skills and capacities are needed i.e., producers don’t know what they don’t know - Lack of confidence in implementing this pathway - Appears to be technically difficult - Producers have frequently received inconsistent, incomplete or complex answers to their questions – this doesn’t help clarify what skills and capacities are needed - Not clear what the common goals are for carbon neutral agriculture in Australia - advisory sector may need specific training on calculating soil carbon and how to design a workshop around this technical area
Transformational	- Reference Group members already experimenting with a range of agricultural technology (agtech) and innovations: - drones, automated weighing and water monitoring (agtech) - trialling different fodder crops (introducing legumes or new cultivars) - involved in animal genetics (improving cattle performance through breeding) - still in early learning about how to get the most value from technologies - Need further advice on how to use new technologies for maximum ROI for the triple bottom line

The mixed responses from the reference groups to the Nexus adaptation pathways highlight the need to avoid any assumption that adaptation pathways are interchangeable for producers. In supporting on-farm adaptations to climate-related changes, a nuanced approach is needed, which accounts for the different values associated with the pathways and provides specific advice related to the adaptation pathway. The findings also highlight the importance of continually generating options for climate change adaptation to enhance the agency of producers to direct their own adaptation pathway. Adaptation support may be best designed not as a single discrete pathway but as an individualised 'package' of adaptation activities with some flexibility to swap in-out activities in response to changing conditions and goals of the producer. While the Nexus reference groups indicated that there is individual capacity to 'adapt' and 'diversify and grow', it is important to recognise individual limits of producers for adapting (whether it is a perceived limitation or an external constraint). This is in recognition that adaptation at the individual producer level also requires an enabling environment since adaptation to climate change does not occur in isolation but is influenced by a complex mix of multiple climatic and non-climatic drivers (Craddock-Henry et al., 2021) that act at both the property level and larger scales (e.g. local community, production region, industry and markets). The sentiments and questionnaire responses from the Northern Victoria, East Gippsland and Northern NSW reference groups reflect this complex adaptation environment.

Climate change adaptation and mitigation is both enabled and constrained by non-structural factors such as human skills, knowledge, self-efficacy and social networks, as well as structural factors, such as the governance of RD&E systems and public and industry investment priorities (Gorddard et al., 2016; Fedele et al., 2019; Wilson et al., 2020, as cited in Craddock-Henry et al., 2021). These factors can play both a supportive and inhibitive role in the experiences of producers responding to climate-related pressures, which may play out as simply coping with change or having the capacity to actively make incremental or transformative change.

4.5.2 Engagement with producers and farm advisors in building capacity for adaptation and transformation

The social research team contributed towards engaging producers and advisers in building capacity for adaptation and transformation in a range of project activities. Producers and advisers were asked to identify and discuss priorities for RD&E, reflect on their participant experience in the Nexus Carbon Neutral Agriculture seminar and facilitating a conversation about what value was gained from reference group members being a part of the Nexus project including thinking about what a future Nexus-like project could entail to add value to what has already been completed.

Identifying extension and advisory service gaps for adaptation and mitigation

The Northern Victoria, East Gippsland and Northern NSW reference groups were asked to think about not only R&D priorities, but also extension and advisory service gaps as part of a group discussion and the adaptive capacity questionnaire. These informal needs analysis activities assisted producers and advisers with identifying where their capacity could be strengthened and how capacity building efforts could be achieved. The reference groups emphasized region-based activities that demonstrated practical adaptation and mitigation options, facilitated producer to producer learning and extended the variety of tactical actions that can be taken in a more effective way. (See Section 6. About future research and recommendations).

Participant feedback from the 'Nexus Carbon Neutral Agriculture' seminar

The 'Nexus carbon neutral agriculture' seminar was attended by 34 seminar participants and 9 NEXUS Project Team members on March 10, 2022. The seminar questionnaire was answered by 25 respondents, which is a 73% response rate. Most of the respondents and attendees at the seminar indicated that they were primary livestock producers (cattle, sheep or cattle and sheep). A small proportion of seminar respondents were non-primary producers and identified as a facilitator, consultant or lecturer.

The ratings and feedback received infers that seminar respondents generally trusted and valued the information presented. Overall, the seminar was rated highly in terms of:

- positively shifting people's level of knowledge on carbon neutral agriculture
- being pitched at the right level for developing a clear understanding about what carbon neutral agriculture is
- motivating further action to be taken i.e., talking with their agricultural advisor about transitioning to carbon neutral agriculture, sharing information with other producers/peer networks, taking practical steps to build their soil carbon or establishing a soil carbon baseline.

The questionnaire responses also indicated there is a demand for and interest in providing similar events in the future with certain factors to consider:

- the focus for future events should be on the practice of reducing methane emissions through livestock management/new feed technologies, as opposed to a broad orientation towards managing soil carbon
- providing a stronger value proposition or cost benefit analysis for transitioning and operating carbon neutral farming systems
- advisory sector may need specific training on calculating soil carbon and how to design a workshop around this technical area

The questionnaire also picked up some scepticism from a few respondents about carbon markets that are considered 'skewed' towards vested interests and the political nature of carbon neutral agriculture. This suggests that going forward, information about this topic area needs to be transparent, clearly positioned in both a political and technical context, and balanced with the trade-offs that might be involved.

The NEXUS project team was informed that a producer discussion group had been formed using the seminar as a basis for recruiting potential members. The discussion group is called the Gippsland Carbon Club. Emma Orgill (East Gippsland Regional Agricultural Landcare Facilitator) will chair/facilitate the discussion group, and the producer members will drive the agenda of the conversations and actions that take place.

Nexus project feedback from the reference groups

Reference group members indicated that there was value in participating in the Nexus project for stimulating new thinking, challenging current thinking, and learning about various adaptations that are currently being practised in the red meat sector. The Case Study Farm method was also considered a value-adding activity to the modelling approach. The Nexus project was critically assessed as being too focused on strategy at the expense of tactics. The approach taken to calculate the GHG emissions was not necessarily considered a precise method. However, if there was to be a Nexus Project 2.0, there is scope to build on what has already been done by focusing on risk management and trade-offs that may be involved in adaptation and mitigation pathways, selecting a case study involving a younger and older producer working together in a mentor/mentee relationship and tracking a case study of a producer implementing strategies to be carbon neutral in real-time, i.e., “watch it happening”.

Strengths of the Nexus project

- Being a case study farm gave you lots of value – having your GHG emissions calculated, adaptation options designed based on your production systems, and the ‘Trees on Farms’ work that was incorporated.
- Being stimulated to engage with “bigger picture thinking about how to adapt to broader challenges”
- Thinking through the options was challenging, educational and enjoyable
- Modelling the impacts on pasture production was a valuable activity
- Project has validated what producers have been doing (adapting) and need to continue doing into the foreseeable future.
- Case study approach using a real farm
- Project has highlighted what farmers are doing in this space – good story to tell, farmers are taking action demonstrated/captured by this project
- Learning what an improved farm system could look like in the future

Weaknesses of Nexus project

- Some scepticism about the GHG calculators: Are they accurate? Are they reflective of farm differences?
- Scepticism with carbon sequestration from woodlots
- GHG emissions – still a lot of unknowns, have very little certainty to make changes
- The carbon story is still a debate – a long way off from being implemented widely
- There is a long journey involved in each pathway from starting point
- Struggled to grasp the directions the project was going in
- Producers can’t respond strategically alone; producers also need to have the ability/options for tactical decisions and actions. Nexus project tended to focus on the strategic, not the tactical
- Covid disrupted project therefore constrained the number of time the reference group and project team was able to meet face to face

What Reference Group members would like to see in a Nexus Project 2.0

Theme 1: Case study selection

- Tracking a case study of a farm implementing strategies to be carbon neutral “watch it happening”
- Different case study selection – target a younger producer who is starting out and pair up with a more experienced producer as a mentor/ interest in focusing on what an innovative producer is doing/top operators are doing and matching this innovator with a producer who is further back along a developmental pathway and work with them to apply certain these strategies on their farm based to build adaptation and innovation capacity in the industry
- Case study to highlight lived experience with adaptation [and mitigation] over a significant time period

Theme 2: Having a different or greater foci on certain elements during the project

- Focus on extreme weather events and how to manage new risks with a focus on risk management (economic, production, social)

- Focus on organic matter – making improvements to soil carbon, carbon footprint, in relation to legislation/policy
- How to navigate through the information highway – how to make a good adaptation decision
- More focus on the triple bottom line in adaptation and mitigation
- Extension of 'low hanging fruit' – this could include things like growing trees in unproductive areas of the farm
- Look at other solutions other than woodlots/biomass for C sequestration
- Lucerne (summer-active pasture species) trials are important/priority
- Greater focus on identifying what the decision points are for each adaptation pathway and what options are available at these various decision points/for each climate scenario (lower, mid and higher) - e.g. what choices do you have when you have surplus feed based on a lower or higher future climate scenario? store it, sell it, agistment to eat it down
- Focus on what are the potentials in each adaptation/mitigation pathway – how to take advantage of the good years including opportunity costs involved, this could also include drought recovery responses from government/industry

General comments/take-home messages

- Agriculture is not going to solve the climate crisis – other sectors/societal practices need to do some heavy lifting – such as investment in large scale renewables
- Don't get distracted by growing trees or paying the carbon tax instead it is about making better economic decisions
- "Cute [and] shiny options are more of a distraction" to good livestock production principles such as efficient use of inputs to maintain or increase outputs over time and applying best practices to livestock and pasture management – this is the most important thing!
- One producer commented that they have been "burnt" by his peers from implementing new practices and approaches to his livestock business – therefore they have concluded that it is better to safely observe an innovator/early adopter who is prepared to take the risks and follow on from their experiences.

4.6 Report on 'Involve and Partner' activity/ies and review implementation success, effect on business performance and opportunities or barrier to further uptake

The Involve and Partner project will demonstrate the use of mixed species pastures to finish lambs in East Gippsland. There is anecdotal evidence in the region that mixed species pastures can achieve higher animal production, which can lead to earlier turnoff times providing flexibility to adapt to the variable climate and the possibility to avoid greenhouse gas emissions. Two demonstrations will be established (summer and winter lamb finishing) comparing pasture and animal production of single-species annual forages with multiple-species mixtures. For each demonstration, pasture measurements (species composition and quality) will be measured twice during the growing season, and lambs will be weighed at the start and end of the trial. The project findings will be communicated through four workshops and field days during the project. This project will be completed in partnership with the Gippsland Agricultural Group. The project contract has been signed and planning for the field experiments and communication activities has been done. Wet conditions have delayed the planned summer trial in 2022/23 and a revised project schedule has been submitted to MLA.

This project will conduct two grazing trials to demonstrate the potential of mixed species pastures to finish lambs in East Gippsland. The trials will be conducted at the Gippsland Agricultural Group research farm located near Bairnsdale in East Gippsland (https://gippslandag.com.au/research-farm/). To replicate the typical lamb production systems in the region, the demonstration trials will be conducted at two times of year to represent a summer and winter lamb finishing system.

Both the summer and winter lamb finishing demonstration trials will be established with 8 ha of a control pasture and 8 ha of multispecies pasture. The area of each pasture type will be arranged as four paddocks of 2 ha each to allow for appropriate rotational grazing strategies to be implemented. A minimum of 50 lambs will be used in each pasture type to provide a realistic semi-commercial scale. The lambs will graze each pasture type for 60-90 days, depending on seasonal conditions.

The winter lamb finishing trial will compare Vortex annual ryegrass as the monoculture ryegrass, which is a mid-heading annual variety used to produce good autumn & winter feed. The multi-species comparison will be made up of Leafmore rape (2.0 kg/ha), Tillage radish (1.0 kg/ha), Express oats (15 kg/ha), Shaftal persian clover (6.0 kg/ha), Dictator 2 barley (8.0 kg/ha) and Fuze annual ryegrass (5.0 kg/ha).

The summer trial will compare a forage brassica as a single species control with a novel multispecies pasture to be defined by the project planning group. The planned single-species treatment is Leafmore rape. The multi-species comparison will be made up of Leafmore rape (1.5 kg/ha), Falcon leafy turnip (0.5 kg/ha), Laser persian clover (2.5 kg/ha), Commander chicory (3.5 kg/ha) and Captain plantain (2 kg/ha).

Pasture and animal measurement will be made throughout the trials. Measurements to be made on the demonstrations include:

- Pasture species composition and quality (including neutral detergent fibre (%), digestibility (%), metabolizable energy (MJ ME/kg DM), and crude protein (%)).
- Animal measurements – individual animal liveweights will be measured on entry and exit from trial.

Data from the trials will be used to calculate animal liveweight gain and animal production per hectare. The costs and benefits of the pasture types will be calculated. Animal and pasture data will be used to estimate intake and total greenhouse gas emissions and emission intensity of production from the pasture types using the Sheep and Beef Greenhouse Accounting Framework which is consistent with MLA and Australian government methodologies.

The project was delayed due to extremely wet conditions in Spring 2022. The winter trial has been sown in April 2023 and it has established well. Grazing will commence in late June/July 2023. The summer trial will be sown in spring 2023 and

4.7 Project communications and engagement with regional reference groups

Over the project, 18 regional reference group meetings were held with 5-7 meetings for each case study (Table 32). In addition, 11 industry events were conducted, with more than 300 people attending Nexus project presentations (Table 33). Several transformational webinars were also presented (co-hosted by the Nexus project and the LPP) covering issues of climate change projections, pasture improvement, animal genetics and alternative markets.

A final project webinar is scheduled to be held on Thursday 15th June 2023.

Other communications activities:

- Scientific conference presentations:
    - New Zealand Grasslands Association, 11 May 2021. Brendan Cullen presentation by videoconference. "Climate change impacts and adaptation strategies for pasture-based industries: Australian perspective".
    - Brendan R Cullen, Matthew T. Harrison, Dianne Mayberry, David H Cobon, Duc-Anh An-Vo, Karen M Christie, Franco Bilotto, Saranika Talukder, Lindsey Perry, Richard J Eckard and Thomas M Davison (2022). Nexus project: pathways for greenhouse gas mitigation and climate change adaptation of Australian livestock industries. Eighth International Greenhouse Gas and Animal Agriculture conference, 5-9 June 2022 (Orlando, Florida, USA - hybrid event).
    - Brendan R Cullen et al. (2023) Exploring profitable, sustainable livestock businesses in an increasingly variable climate. International Grasslands Congress (May 2023). Covington, Kentucky USA.
- Radio interviews:
    - ABC Gippsland (Brendan Cullen, December 2021)
    - ABC Central West NSW (Brendan Cullen, July 2022)
- Print articles:
    - Agriculture Victoria, Sheep Notes newsletter
    - MLA Feedback magazine (Matt Harrison)
    - Nexus project profiled in Gippsland Agricultural Group field day notes
    - MLA Feedback magazine – article on East Gippsland case study (in preparation for winter 2023 edition)

Table 32. Summary of the regional reference group meetings in the Nexus project.

Date	Location	Purpose
		New South Wales
9/02/2020	online	Introduce the project and expectations of reference group.
29/09/2020	online	Identify main climate challenges in region, and potential adaptation options
18/05/2022	Cassilis	Case study farm visit and meeting to review preliminary modelling and define the adaptation options.
11/10/2022	online	Review progress to date and refining adaptation options to be modelled
19/12/2022	online	Review progress to date and refining adaptation options to be modelled
4/4/2023	Tamworth	Feedback on final modelling, social research and identification of RDE priorities emerging from project
		Northern Victoria
27/10/2020	zoom	Introduce the project and expectations of reference group.
3/02/2021	Violet Town	Case study farm visit and identify main climate challenges in region, and potential adaptation options.
29/07/2021	zoom	Review progress to date and refining adaptation options to be modelled
7/04/2022	zoom	Review progress to date and refining adaptation options to be modelled
25/01/2023	Benalla	Feedback on final modelling, social research and identification of RDE priorities emerging from project
		East Gippsland
17/11/2020	zoom	Introduce the project and discuss potential case study farms
16/09/2021	zoom	Introduce the project and expectations of reference group.
30/11/2021	Tambo Crossing/ Bairnsdale	Case study farm tour and reference group meeting to review initial modelling and define adaptation options for farm
10/03/2022	Bairnsdale	Review progress to date and refining adaptation options to be modelled
11/05/2022	zoom	Review progress to date and refining adaptation options to be modelled
13/10/2022	zoom	Review modelling and finalising options, social research survey
1/02/2023	Bairnsdale	Feedback on final modelling, social research and identification of RDE priorities emerging from project

Table 33. Summary of industry presentations conducted in the Nexus project.

Date	Location	Key audience	No. attending	Purpose
1/12/2021	Bairnsdale	Gippsland Ag Group and other interested groups	12	Discuss options for the 'Involve and partner' project with regional representatives for Gipps Ag Group, local cuncil and other interested parties
10/03/2022	Bairnsdale	Open project seminar	31	Seminar on carbon neutral farming - by Richard Eckard. Hosted by the Nexus project.
23/03/2021	Canberra	LPP workshop	30	Nexus project progress presentation to LPP workshop
8/10/2020	zoom	LPP workshop	30	Overview project presentation to LPP workshop
30/05/2022	Sydney	LPP workshop	31	Overview project presentation to LPP workshop
20/11/2019	zoom	SALRC NSW	8	Nexus project overview presentation and discussion about case study farm
7/12/2021	Benalla	SALRC Northern Vic	7	Nexus project update presentation
10/11/2020	zoom	Agriculture Victoria	12	Overview project presentation and discussion of potential collaboration
4/08/2022	zoom	Agribusiness Today Forum	40	Nexus project overview presentation and discussion of early findings
27/10/2022	Bairnsdale	Gippsland Ag Group Spring field day	80	Seminar on options to reduce GHG emissions intensity of livestock production - by Richard Eckard. Hosted by the Nexus project. Field day marquee talking to farmers/service providers about project
26/10/2022	zoom	East Gipps. Agric. Partnership Meeting	20	To promote our Nexus I&P project with potential project partners

4.8 Submission of a minimum of one scientific journal articles for peer review

Three scientific papers have been published during the project:

- Cullen, B., Harrison, M., Mayberry, D., Cobon, D., Davison, T., & Eckard, R. (2021). Climate change impacts and adaptation strategies for pasture-based industries: Australian perspective. NZGA: Research and Practice Series, 17. doi:10.33584/rps.17.2021.3476
- Harrison, M. T., Cullen, B. R., Mayberry, D. E., Cowie, A. L., Bilotto, F., Badgery, W. B., . . . Eckard, R. J. (2021). Carbon myopia: The urgent need for integrated social, economic and environmental action in the livestock sector. GLOBAL CHANGE BIOLOGY, 27(22), 5726-5761. doi:10.1111/gcb.15816

- Cullen, B. R., Ayre, M., Reichelt, N., Nettle, R. A., Hayman, G., Armstrong, D. P., . . . Harrison, M. T. (2021). Climate change adaptation for livestock production in southern Australia: transdisciplinary approaches for integrated solutions. *ANIMAL FRONTIERS*, *11*(5), 30-39. doi:10.1093/af/vfab046

Other papers planned to be published from this research project:

- Cullen et al (2023) Adaption and greenhouse mitigation options in the Australian livestock sector .1. Production and Greenhouse emissions. Agricultural systems (target journal)
- Sinnett et al (2023) Adaption and greenhouse mitigation options in the Australian livestock sector .2. Economic outcomes. Agricultural systems (target journal)
- Reichelt et al. (2023) Understanding the adaptive capacity of red meat producers in south-eastern Australia using co-developed adaptation pathways. WIREs Climate change (target journal)

5 Conclusion

5.1 Key findings

In the Victorian and NSW case studies, the change in climate from what occurred during the period 1986 to 2005 to the climate over the period 2000 to 2019 has decreased pasture growth. Consequently, this has added another cost to each case study farm business. The modelled future climate scenarios are also likely to reduce pasture production and add additional costs to the farm business, but this varies regionally. The impact a changing climate has on the case study farmer businesses depends not only on how the climate changes but also depends on their stage of farming. For example, the Northern Victorian and Northern NSW case studies have both adapted to a changing climate over the past 10-plus years and are likely to be profitable without adaptation (unless the extreme 2050 hot and dry scenario eventuates). However, the East Gippsland case study is at an earlier stage of farming and their business is unlikely to remain profitable, without adaptation, under the modelled climate change scenarios.

Although a changing climate may add extra costs, this research has found that all the case study farmers are likely to remain profitable in most of the future climate scenarios through improving the existing farm business, and increasing the size of the farm business, however it is likely to have the highest total risk (business risk and financial risk). It is important to note, there is not one right alternate future, it depends on the case study farmers goals, stage of life, equity, and attitude to risk.

The more extreme climate scenarios that were modelled, were likely to add the greatest cost to a farm business and improving and growing the business may not increase productivity enough to ensure the business remains as profitable as other investments in the economy under these conditions. However, if there is new technology (in the form of improved pasture varieties that are drought tolerant, and/or improved feed efficiency in livestock along with methods to reduce greenhouse gas emissions cheaply) then the case study farm businesses are likely to remain as profitable as other investments in the economy under the most extreme climate scenario explored.

If there was a price on GHG emissions and if the case study farm businesses paid a share of this cost, and the climate changed in the way explored, then combined this could increase total farm costs and decrease farm profit. This research has demonstrated that if the case study farm businesses sought to reduce emissions to zero (or close to it), then the cost of doing so may be greater than paying their share of the social cost of carbon. However, it needs to be noted that it may be profitable for the farm business to reduce some of total GHG emissions. To reduce the first few units of GHG emissions may cost relatively little, but as more and more pollution is reduced the cost of reducing marginal units of GHG's is likely to increase – marginal thinking is key. Future research could explore the costs and benefits for a farm business of reducing different quantities of GHG emissions. Such research is warranted as an optimised farm system will be operating on a relatively flat part of the whole farm profit function. There may be an initial level of emission reduction at which reducing pollution will not substantially change farm profit. Ultimately, deciding whether to do more to reduce GHG emissions or to continue to farm in a 'business as usual' way and pay their share of the social cost, will depend on the social cost of the GHG emissions, the share of that cost that farmers bear, and the cost the farm business would incur to reduce their greenhouse gas emissions. It is likely that the best option will be a mix of strategies, including lifting productivity to increase capacity to pay for social costs being caused, combined with reducing emissions to the point where the cost of further reductions would be more than the price on those emissions.

A summary of the main findings across regions for the Adapt, Diversify and Grow, and TCN options from the modelling and social research is provided in Table 34. The Adapt option was seen as feasible and leading producers are implementing it. Limitations to the Diversify and Grow option include high land values and constrained workforce so this option may not be suitable for some parts of the industry. The Towards carbon neutral pathway can reduce GHG emissions which will help to retain social license and market access but there is limited knowledge and options available to achieve it. The transformative technology options modelled in the project (improved pasture, improved animal efficiency and methane inhibitor) all showed potential benefits for adaptation and mitigation in future farm systems.

Table 34. Summary of the opportunities/pros and limitations/cons of the Adapt, Diversity and Grow, and Towards Carbon Neutral options.

Option	Opportunities/ Pros	Limitations / Cons
Adapt	• Consistent with existing best practices, leading farmers already doing it. • Small reduction in GHG emissions intensity • Potential for quick return on investment • Extension and advisory services are somewhat established • More defined pathway	• Insufficient to maintain profit under 'hot and dry' climate scenarios. • Small increase in net farm GHG emissions
Diversify and Grow	Compared to Adapt: • Increased profit • Increased production • Diversified income streams – increasing the resilience of rural livelihoods • Can provide a means for farm succession	Compared to Adapt: • Increased variability in profit • Higher financial risk • Increased net GHG farm emissions • Increasing land values can make it unaffordable to purchase additional land resources • May require an expanded farm workforce – access to farm labour is currently constrained.
Towards Carbon neutral	Compared to Adapt: • Reduced net farm GHG emissions • Reduced GHG emissions intensity • Access to supply chains • Maintain social license to continue livestock production	Compared to Adapt: • Lower profit compared to 'Adapt'. • Uncertain goal posts • Limited options to implement on farm • Limited knowledge in industry • Undefined risks involved for the transition • Extension and advisory services are not established • Less defined actions to implement this pathway and ensure market access

In central Queensland, the projected 2030 climate at the studied region will see a reduction in monthly rainfall by more than 10% and an increase in monthly temperature by more than 1^{o}C. The rainfall reduction and temperature increase in the 2030 climate will reduce pasture growth in autumn, spring and summer but increase pasture growth in winter. Increased pasture growth in winter cannot compensate for the reduction in pasture growths in other seasons but can improve animal weight gain in winter, increasing the annual weight gain of selling steers driving income of the beef enterprise. However, the 2030 climate will have a negative impact on profits under all initial land conditions because the sustainable herd size need to be reduced to avoid deteriorating the land condition. To maintain condition of the land the number of animals was reduced in the 2030 climate so total herd profit was reduced despite per head liveweight gain being higher in 2030 owing to higher per head LWG in winter and spring. The 2030 climate will see a reduction in annual beef production as well as the economic viability of the available resources (gross margin per ha).

Improved pasture was demonstrated to be a promising adaptation option in the 2030 climate for Central Queensland, significantly increasing the herd size and enterprise profits while maintaining emission intensity. Improved rumen function can be an option to maintain the enterprise beef production, profit, as well as emission intensity compared to those under the historical climate.

Adaption options would allow to have greater sustainable herd sizes than that without adaptation. Moreover, sustainable herd size varies among the adaptation options, driving the variable costs of production. We founded that improved pasture and rumen functions can improve and maintain, respectively, beef produced per financial year while improving the economic efficiency of the available resources compared to those of the historical baseline.

5.2 Benefits to industry

This is the first project to identify pathways for the livestock industry to both adapt to the changing climate and reduce GHG emissions. The pathways mainly use existing technologies and highlight practical options to achieve adaptation and GHG reductions, and highlight that leading farmers are making changes to adapt and reduce GHG emissions intensity of livestock production. The Nexus project has highlighted a range of future farm options that can maintain profitable livestock businesses in all but the more extreme climate scenarios (i.e., the Hot and Dry scenarios). This will require changes to farm systems, but most of the individual options identified involve incremental improvements in farm inputs and management – however together they make substantial increase to the profit of the farm business. The project highlighted that leading farmers are constantly making changes to their businesses – they are already adapting to the changes that have occurred. Many of the options are considered best management practices, and emphasis needs to be placed on extension of the messages to a larger proportion of the farm population. In other area, research is needed to address new challenges.

The project has also established a series case study farms that can be used in future research and development projects to model the impacts of changes at a whole farm system level, and established a social research methodology to assess the adaptive capacity of the industry to changes.

6 Future research and recommendations

The research, development and extension recommendations from the Nexus project were derived from the modelling results and discussions with the regional reference groups. They are summarised in Table 37, and grouped into 'Feedbase and landscape management', 'Animal genetics and management' and 'Business models' and 'Technology or infrastructure enablers' categories

Table 37. Summary of Research Development and Extension (RDE) issues raised in the Nexus project through modelling and reference group consultation for adaptation to changing climate and mitigation of GHG emissions. The issues are organised by themes and the focus required (R, D, E, or a combination) and regional relevance is provided.

Theme and issue	RDE focus	Region
Feedbase and landscape management		
Pasture improvement and soil fertility to maximise pasture growth for the soil moisture available particularly in a drier and more variable climate. Both the modelling results and the reference groups highlighted this as important for adaptation.	E – largely know technologies.	N Vic, Gipps, NSW
Low-cost options to introduce subtropical grasses into native pastures. The modelling and reference groups both highlighted increasing role for subtropical grasses in the region, but establishment failure is a key risk.	D, E	NSW
Maximise pasture growth during the reliable part of the growing season: this includes strategic use of N fertiliser and gibberellic acid to boost winter growth (modelled) but may also include different species options (including annual and hybrid ryegrasses, cereals). In Central Queensland, this might also include tactically feeding cheap supplement in good seasons for better native pasture recovery.	RDE	N Vic, Gipps, CQ
Options to extend the pasture growing season in response to a contraction of the growing season for 'traditional' temperate species. The focus is on summer-active pasture mixtures (e.g., lucerne) but noting there is a lack of options suited to the climate and soil type in northern Victoria.	RD	N Vic in particular, also Gipps
Pasture combinations at the 'whole farm' level in a changing climate – e.g., what proportion of summer and winter-growing pastures are to match livestock feed demand? The emphasis here is on use of different pasture mixtures in different paddocks, rather than species combinations in the same mix.	RDE	All
Role of kikuyu-annual ryegrass (or cereal crop) systems in livestock production. These pastures have been used extensively in dairy production in coastal NSW and southern Qld, but not as much in Victoria.	RDE	Gipps
Pasture quality – use of genetic improvement (Gipps, N Vic) or management (NSW) to improve pasture energy content (MJ ME/kg DM).	RDE	All
Design and develop pasture systems to deliver methane mitigation – how to use alternative species with plant secondary	RDE	All

compounds (e.g., biserrulla) to reduce methane emissions from livestock (pasture mixtures, spatial arrangement of pasture, grazing management) including understanding of tradeoffs with pasture production and persistence.		
Grazing methods guidelines under warmer temperatures to maximise pasture persistence (e.g., time of grazing and grazing residuals)	RDE	All
Trees on farm – identify synergies with livestock production and opportunities for co-benefits (biodiversity, shade, C sequestration). Planning location and species of trees at fam scale for maximum benefits.	RDE	All
Broad recommendation from N Vic group for a dedicated feedbase RDE program addressing known limitations (fertility, pest and disease, grazing) and emerging issues in the changing climate. This could encompass many of the issues raised in the 'Feedbase and landscape management' section).	RDE	All
Animal genetics and management		
Grazing management in a changing climate – linked to the changes in feedbase, there is a need to re-evaluate stocking rates and stocking policies (e.g., earlier spring lambing to take advantage of increased winter growth and reduce the risk of a poor spring season).	DE	All
Methane inhibitors that can be delivered in pasture-based livestock production systems (e.g., rumen bolus, lick, in water). Seen as a key to reducing GHG emissions on farm. R&D is occurring but greater emphasis on pasture-based systems needed.	RDE	All
Improved feed conversion efficiency (e.g., through lower mature weight of livestock) – delivers both adaptation (lower feed requirement per animal) and mitigation (less methane per animal) benefits.	RDE	All
Role of stock containment in adaptation and mitigation – set-up, animal nutrition, and additional benefits like autumn saving. May provide an opportunity to feed supplements to reduce methane emissions.	E	All
Animal health under a changing climate (including heat stress, new pests and diseases).	RDE	All
On-farm measurement of methane emissions – important for producers to have confidence in the mitigation strategies that they are implementing	RD	All
Business models		
'Grow the business' was identified as a profitable option but with higher year-to-year variability. Develop risk management approaches for growing businesses, including the role of extreme climate events/natural disasters (see below), spatial diversification (see below), alternative markets (e.g., carbon and biodiversity) and off-farm income. • Risk management approaches need further consideration across all the options, not just the 'Grow' option.	RDE	All
Spatial diversification – complementary pasture growth patterns, different climate risks and different expose to extreme: flood, fire	RDE	All

(and maybe drought?) – was modelled as having some benefits but further research required to understand the best places to invest.		
Business structure and management options to reduce the risk of extreme climate events/natural disasters (bushfire, multi-year drought, floods). These individual extreme events were not fully explored in the Nexus project but merit further investigation, may link to other recommendations such as spatial diversification.	RDE	all
Advisory services needed for pathway towards carbon neutral (lack of knowledge and skills in regions).	RDE	All
Better definition of a C neutral farm – scope 3 emissions for traded livestock, accounting for all changes (losses and gains in soil carbon), adaptation and mitigation tradeoffs (e.g., trading livestock is an opportunity to manage climate variability, but if the business needs to account for the embedded GHG emissions in the purchased livestock it is a disincentive.	RDE	All
Agrivoltaic systems – grazing under solar panels for income diversification. It was not prioritised by reference groups in the Nexus project but some interest to investigate especially where cattle grazing can be implemented.	R	N Vic, NSW
Forestry and Livestock production – deeper investigation in the forestry as a C sink to off-set GHG emissions as well as income diversification (costs and benefits)	RDE	All
Understanding and improving decision making – e.g., in drought many people don't act until it is too late.	RDE	All
Technology or infrastructure enablers		
Improved seasonal forecasts and use of soil moisture monitoring to aid decision making on farm (informing tactical responses to changing climate conditions)	RDE	all
Livestock weight monitoring linked with feed quality and quantity (eg Optiweigh systems for sheep). Allows for real time data collection to make earlier decisions	RDE	NSW
In field NIR sensors to measure feed quality (needs to be well calibrated and applicable to a very diverse feedbase)	RD	NSW
On farm infrastructure – increasing feed storage, increase dam size, feeding infrastructure to reduce wastage. Leading farmers have invested in infrastructure such as this to reduce climate risks, but other farmers have not.	E	All

Priority recommendations for extension and advisory services

Based on our engagement with the Northern Victoria, East Gippsland and Northern New South Wales reference groups, we provide the following recommendations for extension and advisory services across the following themes: basic scientific research, communications and engagement of knowledge networks, advisory capacity building, extension and advisory activities and farm system data collection and decision-making tools.

Theme: Science-based research in the regions

Recommendation 1	***Increase basic science activities in Australia's red meat production regions that are funded by public, industry and/or private research organisations***
Description/Rationale	General sentiment from the Nexus reference groups that there is not enough basic science being done in their regions to provide the scientific information about soil health, pasture species and carbon sequestration using biomass.
Potential Benefit	Advisers and producers would have better access to rigorous and science-based evidence and therefore greater confidence in adapting and mitigating GHG emissions in livestock production systems.
Timeframe	Mid-long term

Recommendation 2	***Fund and support commercial farm trials to 'test' adaptation strategies and tactics***
Description/Rationale	Testing how robust certain modelled and promoted adaptations are over 3-5 years, rather than basing decisions on evidence that has been tested over one season only or as a one-off response to an extreme weather event.
Potential Benefit	Increasing producer engagement and confidence in adaptation and mitigation strategies (pathways) from having access to on-farm evidence of their mid-long-term effectiveness.
Timeframe	Mid-long term

Theme: Communications and engagement of knowledge networks

Recommendation 3	***Develop a strategic communications and engagement plan about adaptation and mitigation options for climate related change***
Description	A communications and engagement plan built by industry would be useful for: aligning and coordinating messaging and engagement activities about climate change adaptation and mitigation that combines strategies and tactics. The Plan would need to decide how to frame adaptation and mitigation e.g., as modelled pathways, packaged options, tailored opportunities etc. The Plan should incorporate the interests of local producers and other stakeholders (e.g., land and water authorities, Landcare groups) for communicating climate change adaptation and mitigation in agriculture. At least, the Plan should have the endorsement of the local producers and relevant stakeholders. The Plan could include: 1) ways to connect with less engaged producers in climate change adaptation and mitigation, 2) a guide to navigating the glut of research and information about climate change adaptation and mitigation, 3) greater profiling of producers who are doing adaptation and mitigation under various climate conditions.
Potential Benefit	Greater producer confidence in climate change adaptation and mitigation messaging based on consistency of messaging and aligning with a range of producer values and goals.
Timeframe	Immediately

Recommendation 4	***Reinforce and support peer to peer learning through region-based knowledge networks regarding climate change adaptation and mitigation***
Description	Local advisers could map the regional knowledge networks that could initiate and maintain conversations about responding to climate related changes in red meat production/agriculture more generally. This mapping could include producer-based groups, (for example: a local producer discussion group about carbon farming was formed in one of the Nexus case study regions and facilitated by a regional Agricultural Landcare Facilitator), local agri-business networks, Landcare groups etc. The focus would be on engaging producers, advisers and researchers in conversations about climate change adaptation and mitigation conversations at events/network spaces where this topic is already being talk about or providing a neutral territory or forum where they can be held. The aim would be to share experiences, knowledge and resources within and across region-based knowledge networks. Part of supporting peer to peer learning through regional knowledge networks is to provide facilitated conversations by a leading producer, agricultural adviser or professional facilitator. The learning agenda could include: - learning about the Nexus adaptation pathways - other producers who are applying adaptation and mitigation R&D on their own farms - learning from other production regions
Potential Benefit	Keeping the adaptation and mitigation conversations going at a practical level.
Timeframe	Over the next 12-24 months

Theme: advisory capacity building

Recommendation 5	***Enhance the skills and knowledge of advisers and service providers in carbon neutral agriculture***
Description	Designing and delivering professional development for agricultural advisers and service providers. Potential topics could include: - providing a stronger value proposition or cost benefit analysis for transitioning and operating carbon neutral livestock production systems - specific training on calculating soil carbon and how to design a workshop around this technical area MLA or state government agricultural departments stepping into the role of knowledge broker to centralise, review and promote reliable information and knowledge about GHG mitigation and carbon neutral agriculture. MLA and other service providers need to form stronger partnerships and greater alliances for long term coordination and delivery of adaption and mitigation programs. There is strength in delivering programs as a collective effort.

Potential Benefit	Ensuring that there are advisers and services that match the interests and needs of livestock producers. Providing a reliable and convenient 'one-stop-shop' to deliver climate change adaptation and mitigation information for producers and advisers – getting everyone in the industry onto the 'same page'.
Timeframe	Over the next 12-24 months

Theme: Extension and advisory activities

Recommendation 6	***Annual delivery of a sequenced workshop series about climate change adaptation and mitigation that includes both strategic planning and tactical practices relevant to a region.***
Description	MLA, state agriculture departments, universities and private consultancy firms may already deliver climate change related workshops that can be tapped into. However, this recommendation is about curating regionally relevant workshop series that could draw on the Nexus research, and other adaptation and mitigation options that are being implemented in the region. The workshop series could include on-farm adaptation and mitigation, as well as linking these practices with red meat value chains (getting processor/food retailers involved). Potential workshop topics mentioned by the Nexus reference groups were: - tactical decision making/change management in conjunction with climate/weather forecasts: to include highlighting those producers who made good decisions in extreme weather events and other production pressures - Refresher on stock containment - Refresher on soil fertility - Need better indicators and apps for assessing feedbase quality/energy potential/diversity based on live data from the field e.g. being able to use a handheld device rather than relying on sending feed samples for analysis by laboratories that can take too long
Potential Benefit	Continually raising awareness and upskilling producers in adaptation and mitigation strategies and tactics for responding to regional changes in climate.
Timeframe	Rolling annual offering

Recommendation 7	***Develop a new series of demonstration farms showcasing adaptation and mitigation options as well as an assessment of the impacts/trade-offs/synergies from implementing these options in a commercial context***
Description	There is a call from the reference groups to build the 'look, see' concept for demonstrating adaptation and mitigation options in practice. MLA's PDS or similar program would aim to demonstrate and evaluate the impacts of a range of adaptation and mitigation approaches on commercial pasture-based livestock properties situated in different agro-climates using on one or more of the following criteria: - risk management - business planning and performance

	- enterprise mix - pasture productivity and persistence (including mixed pasture systems, trialling methane reducing pasture species and interactions with animal health and productivity) - Better management of extensive systems and interventions with other methods
Potential Benefit	Enhancing producer awareness and capability to navigate the risks/trade-offs/opportunities with adapting and mitigating GHG emissions.
Timeframe	ASAP and ongoing

Theme: Farm system data collection and decision-making tools at the property level

Recommendation 8	***Continue to develop standardized ways to collected property scale farm system data with integrating software.***
Description	The monitoring and evaluation of implementing tactical options and strategic planning for adaptation and mitigation would be better supported by having standardized ways to collect/input farm system data as well as an online platform/software to integrate different data sources to provide an overall 'picture' of the livestock business/production performance. This would also assist in having greater capacity to evaluate the strengths and weaknesses over time of applying various tactical options in relation to a livestock business strategic plan. The potential is to present adaptation and mitigation as a flexible pathway with opportunities to swap out/in options, test and compare a range of options over time. This could involve research/economic analysis or decision software /app for comparing the swap in or out scenarios depending on your farm situation. Other points to consider: - develop adaptation/mitigation tools with the same practical value as the NSW drought feeder tool - Excel is the current data dumping ground for some of the reference group producers, which does not provide an efficient monitoring and evaluation function or integration capacity. - Need expertise or build the capacity of producers in interpreting complex data sets collected this includes ground truthing of remote sensing data/AI outputs, as well as understanding the basic parameters used in big data collection. - Need to refine what actions should be triggered based on the live data being collected.
Potential Benefit	Increasing the chances of producers making more informed and more timely management decisions about adaptation and mitigation options.
Timeframe	Over the next 12-24 months

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8 Appendices

8.1 Costs and prices used in the economic analysis of East Gippsland, northern Victoria and NSW case studies

The Adapt, Towards Carbon Neutral, and Diversify and Grow options and associated costs for the East Gippsland, northern Victoria and northern NSW case study farms are presented in Tables 1-3.

Table 1. Summary of Base farm, Adapt, Towards Carbon Neutral and Diversify and Grow options for the East Gippsland case study.

Option	Changes implemented	Associated cost
Adapt	1. Increase feed supply • Establish high performing perennial pastures on 225 ha at Tambo Crossing. • Reduce paddock size as a part of improving the pastures, create ten 20 ha paddocks which requires fencing and water troughs. • Apply gibberellic Acid (10 g/ha to Phalaris pasture and 20g/ha to other species) and urea (40 kg N/ha) on improved pastures (406 ha) for an extra 800 kg/ha of pasture in the winter. 2. Increase animal performance • Increase lambing percentage from 150 to 165% (through shelterbelts and better management of twin and triplet bearing ewes). • Genetically superior cattle: 5% improvement in animal growth rates/turnoff weights and 5% improvement in calving rates in heifers. 3. Reduce greenhouse gas emissions • Sell wethers at 35kg (instead of 44kg) and sold at end of November (instead of January). • Plant 12ha of trees on unproductive areas of the farm in areas that will provide shelter to ewes bearing multiples.	1. Increase feed supply • Establish high performing perennial pastures costed ○ $432/ha in year 1 (costs for sprays, capital fertiliser, seed cost, contract sowing and lime) plus in year 10 lime applied $59/ha (require 2.5t lime/ha) and weed control $29/ha • Fencing cost $1,990/km plus cost of labour $1,000/km • Water cost $2,700/ trough in paddock plus $1,000/km for pipes • Urea $600/t spread (required 16t), gibberellic acid $31/ha 2. Reduce greenhouse gas emissions. • Planting tree costed $1,390/ha in year 1 to establish; $250/ha in year 2 for weed control; $500/ha in year 4 to prune; $600/ha in year 6 to prune and $700/ha in year 8 to prune and $45/ha in years not prune (co-benefit $2,100/ha).
Towards Carbon Neutral	All changes in the 'Adapt' option plus: • Reduce livestock emissions. Feeder in paddock with all calves fed 2 kg grain/day in Feb, which increase their growth rate to 1.5kg/day and 3NOP is added to feeder. Earlier finishing. • Diversify activity mix through agroforestry, which can also be used to offset emissions (80ha is purchased adjacent to property).	• Reduce livestock emissions. Feeding steers costed 30c/hd.day for 3NOP feeding, $4,500 for portable feeders (2.5t per feeder, requires 5 feeder) for 90 days • Forestry costed $10,000/ha for land purchase, $1,510/ha in year 1 to establish, $200/ha in year 2 weed control, rates and insurance $45/ha for, tree maintenance cost of $20/ha, and labour $5,000 p.a.
Diversify and grow	All changes in the 'Adapt' option plus: • Purchase additional 410ha land in Ensay, stocked at 14 DSE/ha.	Land purchased at a cost of $10,000/ha, capital cost of buying in the DSE $70, extra GM/DSE to be around $55, $80,000 capital investment in machinery.

Table 2. Summary of Base farm, Adapt, Towards Carbon Neutral and Diversify and Grow options for the northern Victoria case study.

Option	Changes implemented	Associated cost
Adapt	1. Increase feed supply • Establish high performing perennial pastures on 100 ha at Violet Town. • Reduce paddock size to 20 ha (requires fencing and water troughs). • Purchase 200 ha improved land in Violet Town (reduce stocking rate). • Apply Gibberellic Acid (10 g/ha) and Urea (40 kg N/ha) in the winter on 837ha to grow extra 800kg/ha. 2. Increase animal performance • Increase lambing percentage from 140 to 155% (through shelterbelts and better management of twin and triplet bearing ewes). • Move lambing and calving a month earlier and sell one month earlier. 3. Reduce greenhouse gas emissions • Plant 10 ha of trees on unproductive areas of the farm.	1. Increase feed supply • Pasture establishment: costed $500/ha in year 1 plus in year 10 lime applied $59/ha (require 2.5t lime/ha) and weed control $29ha • Fencing cost $8,000/km • Water cost $2,700/ trough in paddock + $1,000/km for pipes • Purchase 200 ha improved land costed $12,500/ha • Urea $600/t spread (require 167t), gibberellic Acid $31/ha 2. Reduce greenhouse gas emissions • Planting tree costed $1,390/ha in year 1 to establish; $250/ha in year 2 for weed control; $500/ha in year 4 to prune; $600/ha in year 6 to prune and $700/ha in year 8 to prune and $45/ha in years not prune.
Towards Carbon Neutral	All changes in the 'Adapt' option plus: • Reduce livestock emissions: ○ Wean steers then finish in containment area: aim so that can feed an additive to reduce their methane emissions by 70% with 3-NOP + higher growth rates so turnoff earlier. ○ Replacement ewe lambs will be fed in containment feeding for the two months of summer (November and December). With a 5% increase in the lambing percentage. • Diversify activity mix through forestry, which can also be used to offset emissions. It is assumed 220ha is purchased and will be used for forestry as well as to offset carbon emissions from the farm business costed	• Reduce livestock emissions ○ Wean steers then finish in containment area costed ▪ Five portable feeders (2.5t per feeder $4,500 each); compacted earthen pad $23,000; 3-NOP in feedlot 0.30 cents per day for 107 days; and additional capital equipment (for auger/silo/ water system) $40,000 ○ Replacement ewe lambs will be fed in containment costed ▪ 3-NOP in feedlot: 0.30 cents per day for 59 days; and capital cost of two containment lots each 500 square meter cost $8,000, Water cost $2,700/ trough (require 2 troughs) and $1,000/km for pipes, 2 * $6,000/feeder • Forestry costed $12,500/ha for land purchase, $1,510/ha to establish, $200/ha in year 2 weed control, rates and insurance $45/ha, tree maintenance cost of $20/ha, and labour $5,000 p.a.
Diversify and grow	All changes in the 'Adapt' option plus: • 400 hectares of phalaris/clover pasture was purchased in south-west Victoria (Carpendeit) and stocked at 18 DSE/ha.	Costed $10,273,840 for purchasing land, livestock and machinery plus additional labour costs $180,000, rates $30,000, Insurance $10,000, farm repairs and maintenance $5,000 and other $5,000.

Table 3. Summary of the Base farm, Adapt, Towards Carbon Neutral and Diversify and Grow options for the northern NSW case study.

Option	Changes implemented	Associated cost
Adapt	1. Increase feed supply • Increase arable area of farm from 320 to 500 ha, and sow arable area to tropical grass/sub clover mix. Area of native pasture reduced (Replacing native pastures with tropical grasses on 180ha). • As part of the pasture improvement, it is assumed that paddock sizes were reduced (which required fencing and water troughs). 2. Increase animal performance • increase in lamb survival of twins/triplets from 80 to 90%. 3. Reduce greenhouse gas emissions • Plant 10 ha of trees on unproductive areas of the farm in areas that will provide shelter to ewes bearing multiples (co-benefit).	1. Increase feed supply • Replacing native pastures with tropical grasses costed $500/ha, 100/ha to remove rocks plus additional cost $177/ha for spray in year 10 • Fencing cost $8,000/km (require 1.8 km fencing) • Water cost $1,200/ trough in paddock plus $300 for mats and $1,000/km for pipes 2. Reduce greenhouse gas emissions • Planting tree) which costed $1,390/ha in year 1 to establish; $250/ha in year 2 for weed control; and $45/ha other years.
Towards Carbon Neutral	All changes in the 'Adapt' option plus: • Reduce livestock emissions: ○ Feed steers 2 kg grain/day with 3-NOP (30% methane reduction) for 60 days to finish earlier. It costed $4,500/portable feeder, (requires 3 feeders) ○ Feed prime lamb 0.25kg grain/day for 60 days with 3-NOP which required 5 feeders • Plan 20% of non-arable area to trees (264 ha)	• Reduce livestock emissions ○ Feed steers with 3-NOP costed ▪ portable feeders $4,500/feeder (requires 3 feeders) ▪ 3-NOP 0.30 cents/day for 60 days ○ Feed prime lamb with 3-NOP costed ▪ portable feeder $6000/feeder (requires 5 feeders) ▪ 3-NOP costed 0.30cents/day for 60 days • Plant 20% of non-arable area to trees (264 ha) which costed $1,390/ha in year 1 to establish; $250/ha in year 2 for weed control; and $45/ha other years.
Diversify and grow	All changes in the 'Adapt' option plus: • Purchase 1000 ha in Binnaway	Purchased land costed $6,000/ha, extra livestock purchased at $100/DSE, additional ute and motor bike allowed $100,000.

8.2 Price distributions used for the East Gippsland, northern Victoria and NSW case studies

Probability distributions were fitted to data sourced from Thomas Elder for the period 2011 to 2021 (data was CPI adjusted). (Distribution was truncated to P1 and P99). Price distributions for different products are shown in Figures 1-10. The same price distributions were used for all climate scenarios.

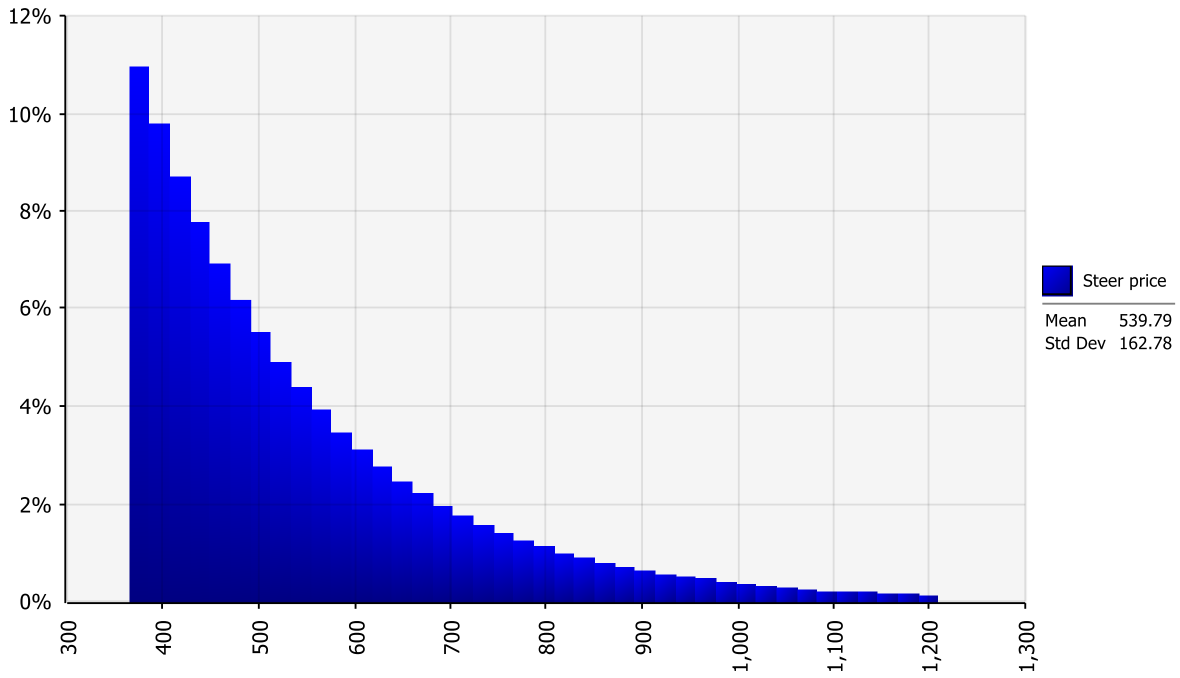


Figure 1. Price (c/kg cwt) for steers

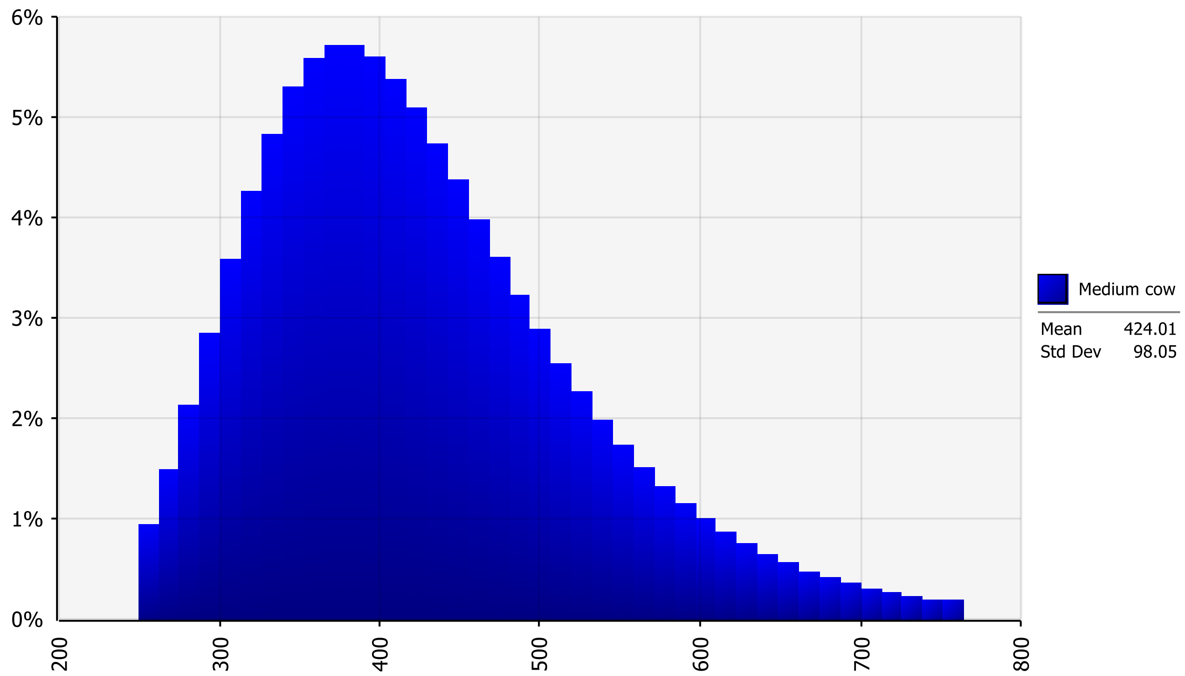


Figure 2. Price (c/kg cwt) for cull cows

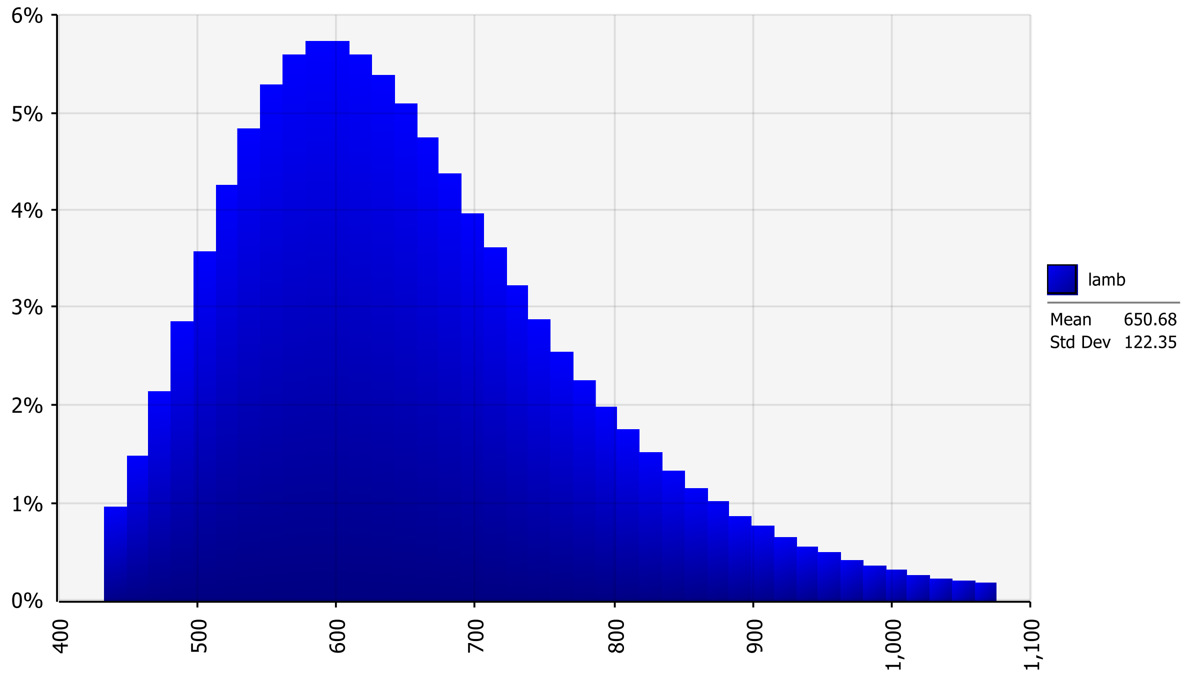


Figure 3. Price (c/kg cwt) for lamb

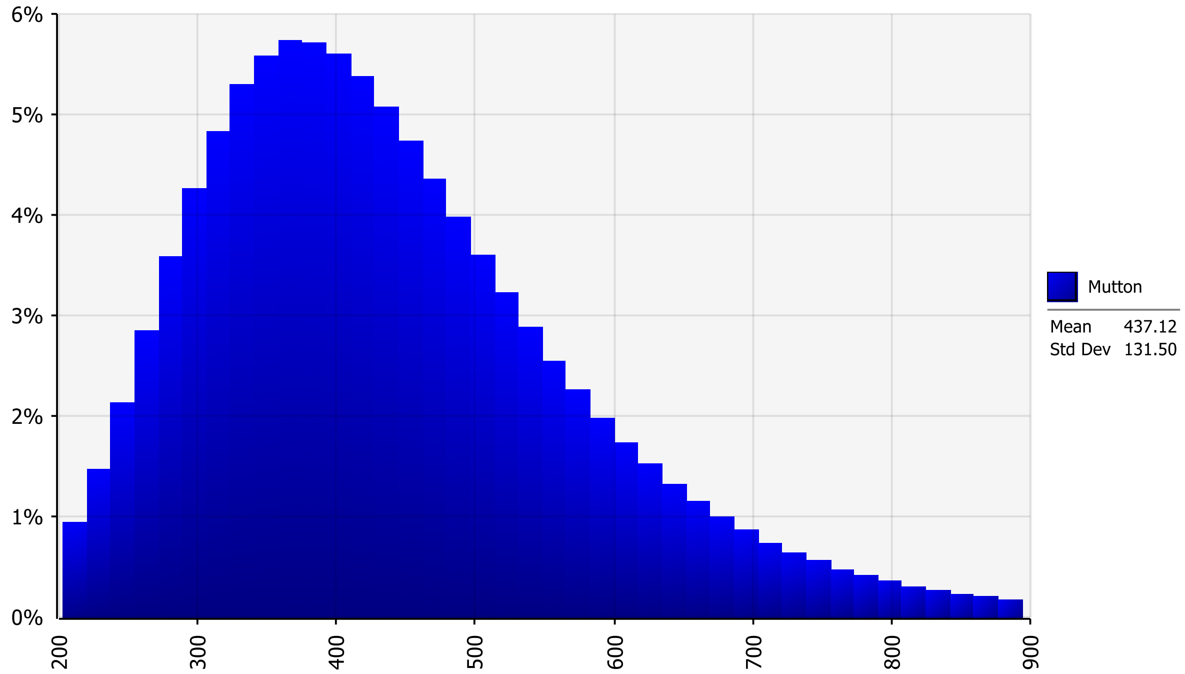


Figure 4. Price (c/kg cwt) cast for age ewes.

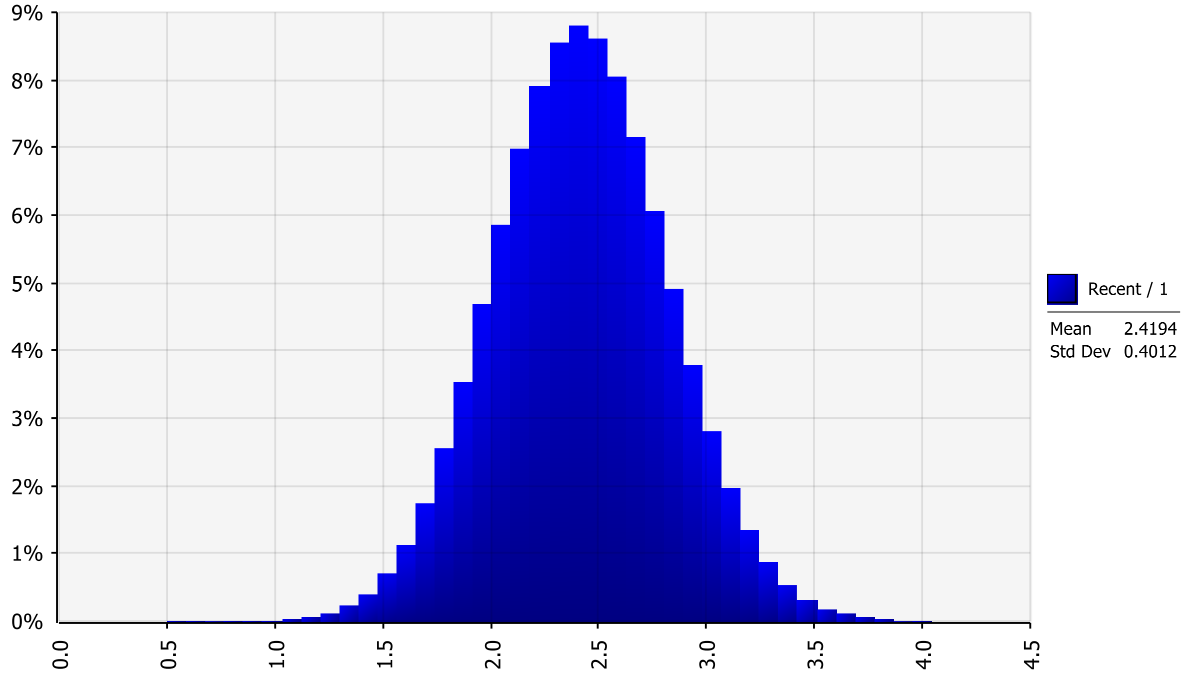


Figure 5. Price (c/MJ ME) for feed purchased for the East Gippsland case study. (Note: If 1000kg of supplementary feed is purchased and it has 12MJME, this equates to buying 12,000MJME at an average price of 2.5c/MJME this makes the average $/t of purchased feed at $300/t.)

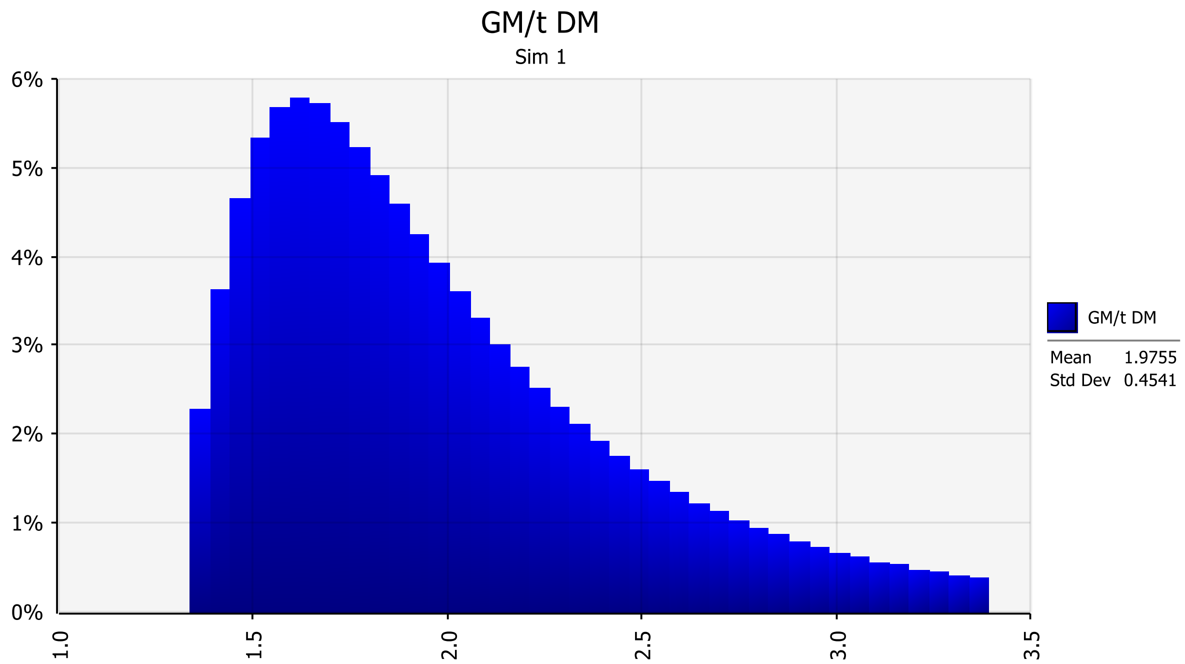


Figure 6. Price (c/MJ ME) for feed sold for the East Gippsland case study. (Note: If 1000kg of feed is sold as hay and it has 8MJME, this equates to buying 8,000MJME at an average price of 2c/MJME this makes the average $/t of feed sold valued at $160/t.)

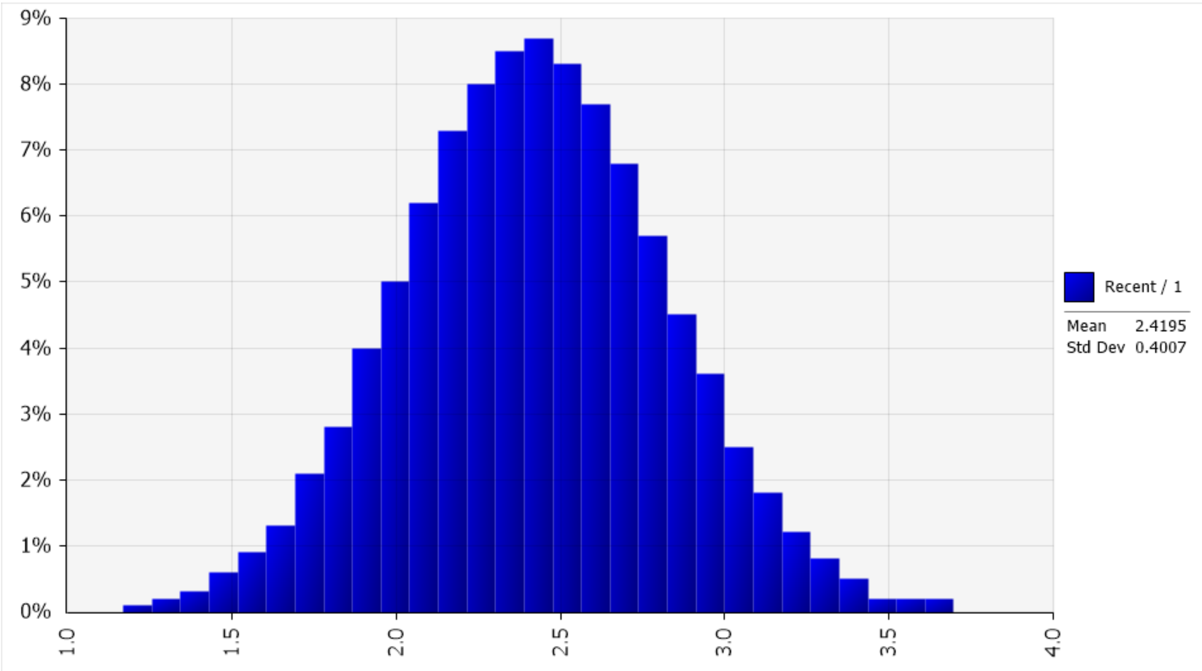


Figure 7. Price (c/MJ ME) for feed purchased for the northern Victoria case study.

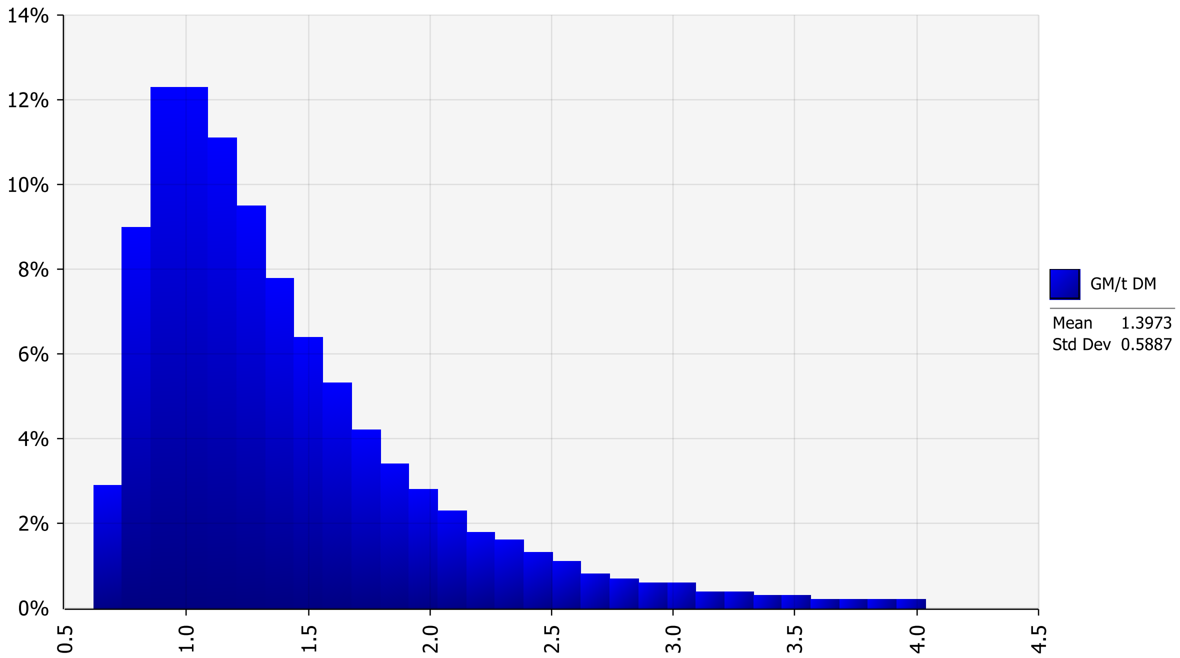


Figure 8. Price (c/MJ ME) for feed sold the northern Victoria case study.

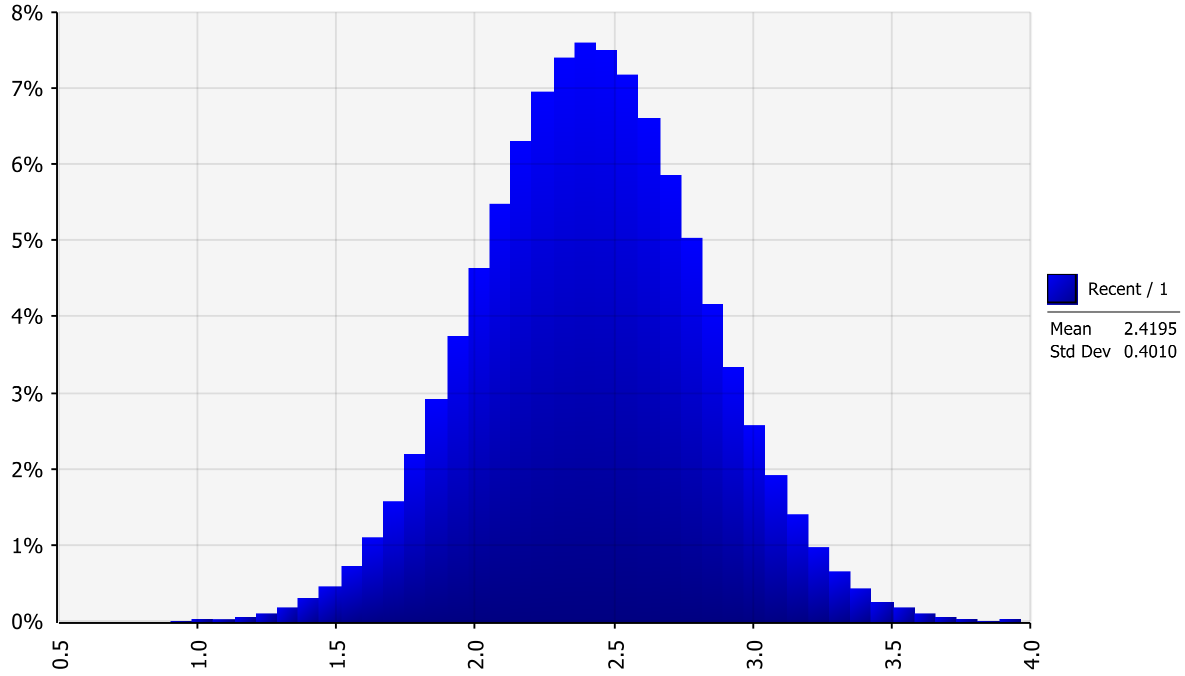


Figure 9. Price (c/MJ ME) for feed purchased the northern NSW case study.

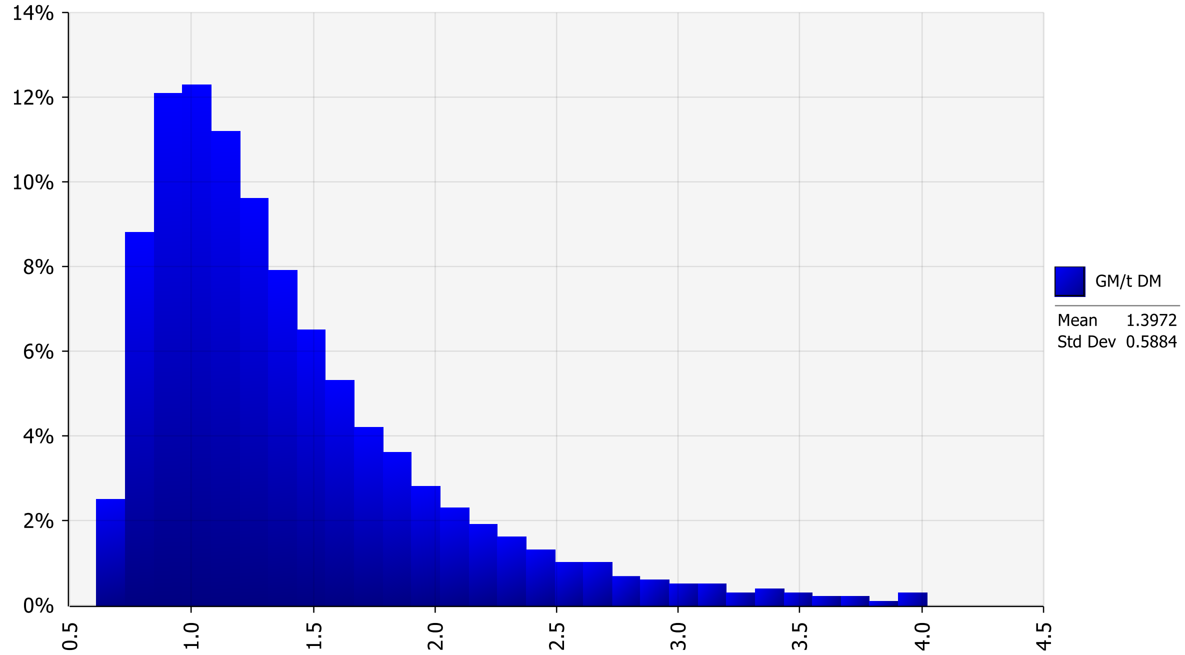


Figure 10. Price (c/MJ ME) for feed sold the northern NSW case study.

8.3 Central Queensland

Introduction

Pasture-based livestock production systems around the world are facing the challenges of adapting to the changing climate. Climate change projections indicate warmer temperatures across Australia and changes to rainfall patterns (CSIRO and Bureau of Meteorology 2015). Projections for future rainfall vary regionally, with no consistent trend projected in northern Australia however an increase in temperatures and the frequency and intensity of extreme climate events (such as heatwaves, drought and extreme rainfall) is predicted. There is a lack of knowledge of the impacts and adaptation methods to maintain production and profitability of farm businesses.

Options for adapting to the future climate include changing the feedbase (e.g., deep rooted or winter-active species), breeding and genetic selection of animals for reproductive performance, use of shelter and altering stocking rates.

This project has explored the impacts and opportunities and costs of adaptation in a livestock business in central Queensland for the projected climate in 2030.

Materials and methods

Australian beef farming occurs across diverse climatic zones, but the dominant extensive beef operations occur in northern tropical and subtropical regions that experiences cold dry winters and hot wet summers. Queensland is the most important state in beef production. We undertook a case study of a typical beef enterprise near Moura in Central Queensland representing the typical climatic variation in subtropical northern Australia.

Case study farm

The property is located south-east of Moura (Latitude/longitude: -24.59/150.09) and has a total area of 8800 ha, average annual precipitation of 630 mm (148 years), long-term annual mean temperature of 21.4^{o}C and average woody vegetation cover of 1.3%. Land types include Brigalow with blackbutt (Dawson gum) (65%), Poplar box with shrubby understorey (27%), Blue gum / river red gum flats (3%), Brigalow softwood scrub (3%), Mountain coolibah woodlands (2%), Softwood scrub (<1%) (Figure 1). Soil types include Brigalow belah, red loams, and black clay with mostly improved pastures. Water use is currently all surface water from dams.

The sustainable herd size is 3300 head (close to 3300 AE) of cows, calves, steers, bullocks and bulls. The controlled mating program joins females in December, January, February with calving in late spring/early summer. Average weaning rate of mature cows is 90% (we could not replicate this level in the modelling). Animal numbers are adjusted due to seasonal conditions, but the objective is to keep cows until 18 years and steers until 600kg (usually 3.5 years). Average birthweight is 38 kg with an average growth rate of 0.5kg/d.

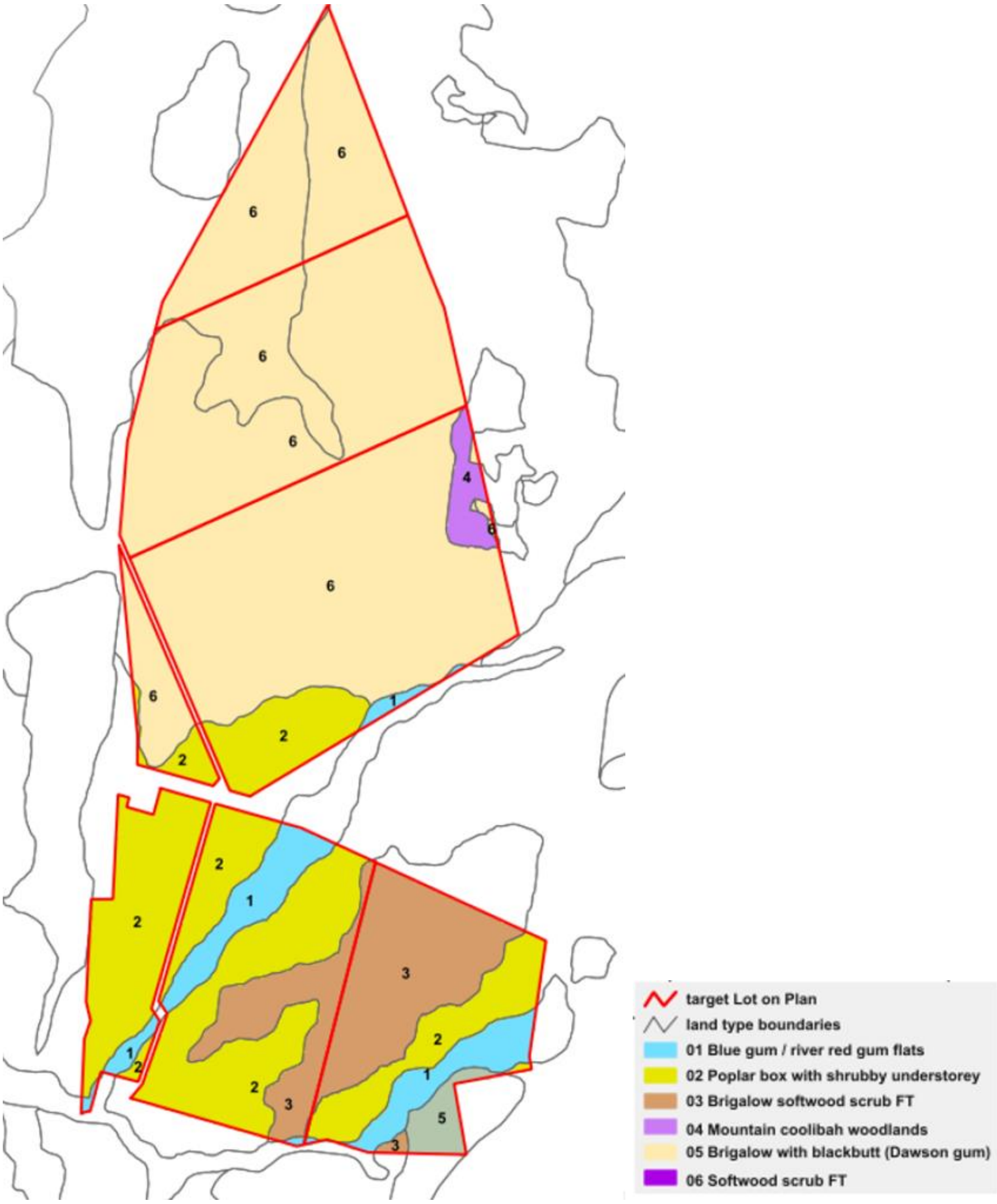


Figure 1. The land-types on the Moura block

Historical (baseline) and 2030 climate data

We sourced historical weather data for the case study from meteorological archives (http://www.longpaddock.qld.gov.au/silo). Historical climate data assumed as baseline were measured from 1 January 1975 to 31 December 2013 on a daily time-step and were used to produce future climate data for the location. Monthly average rainfall (1975-2013) at the site shows a summer-dominant pattern (Figure 2).

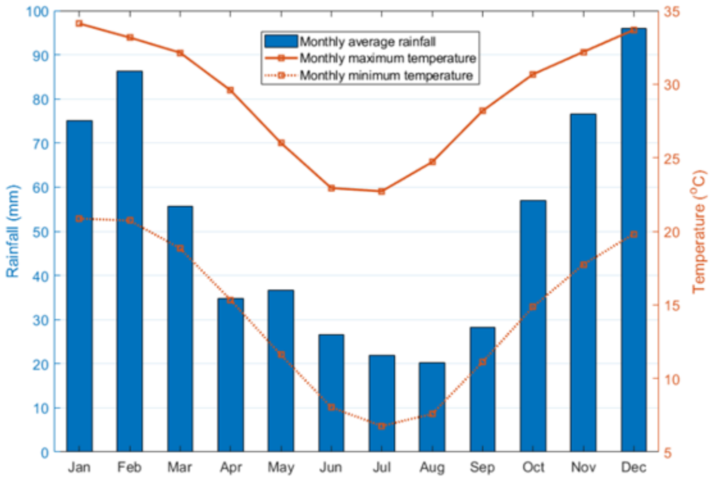


Figure 2. Monthly average rainfall, minimum and maximum temperature for the historical baseline (1975 to 2013) at Moura.

The future climate for Australian cluster East Coast 2030 was derived from the AR5 projections change scenario RCP 8.5 using the future projections for monthly changes in temperature and rainfall (see Figure 3 https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-futures-tool/projections/). We enter these values (see Table 1) into the change calculator prepared and described by Harrison et al. (2016) to perturb the historical daily climate data (1975-2013) with the change factors and generate a climate file for 2030. These historical and 2030 climate files are then used in GRASP for simulation of pasture growth, TSDM, utilisation, animal intake and other variables – the growth variable will then be used in CLEM for animal and other herd output.

		January Mean Surface Temperature (C)			
		Slightly Warmer < 0.50	Warmer 0.50 to 1.50	Hotter 1.50 to 3.00	Much Hotter > 3.00
January Rainfall (%)	Much Wetter > 15.00	1 of 48 (2%)	9 of 48 (19%)		
	Wetter 5.00 to 15.00		6 of 48 (12%)	1 of 48 (2%)	
	Little Change -5.00 to 5.00	1 of 48 (2%)	8 of 48 (17%)		
	Drier -15.00 to -5.00	1 of 48 (2%)	16 of 48 (33%)	1 of 48 (2%)	
	Much Drier < -15.00		2 of 48 (4%)	2 of 48 (4%)	

Consensus	Proportion of models
Not projected	No models
Very Low	< 10%
Low	10% - 33%
Moderate	33% - 66%
High	66% - 90%
Very High	> 90%

Figure 3. Data from the future projections tool for East Coast cluster showing moderate consensus of January rainfall at -10% (5-15%) and temperature at +1°C (0.5-1.0°C) for 2030.

Table 1. Monthly climate change factors for rainfall and temperature for East Coast. Rainfall and temperature change factors were estimated at Moura based on the method developed in Harrison et al. (2016) that allowed us to produce future climate data from the projected climate change with the increased climate variability (more climate extreme events).

Month	Rainfall (%)	Mean Temperature (°C)	Min Temperature (°C)	Max Temperature (°C)	Rainfall change factor	Temperature change factor
January	-10	1	1	1	0.90	1.03
February	-10	1	1	1	0.90	1.03
March	-10	1	1	1	0.90	1.03
April	-10	1	1	1	0.90	1.03
May	-16*	1	1	1	0.84	1.04
June	-16*	1	1	1	0.84	1.04
July	-16*	1	1	1	0.84	1.04
August	-16*	1	1	1	0.84	1.04
September	-16*	1	1	1	0.84	1.04
October	-16*	1	1	2.25	0.84	1.07
November	0	1	1	1	1.00	1.03
December	0	1	1	1	1.00	1.03

*Climate change projection for these months is greater than 15% reduction in rainfall
Source: CLIMATE FUTUREs (2030) – EAST COAST

Pasture growth

Pasture growth was simulated with the Cedar version of GRASP (Windows). All simulations were run at a daily time step over the period 1975-2013 using patched point climate data for Moura from the SILO database as input to the historical-climate simulations, and 2030 climate data used as described above. Soil attributes, land and pasture (Table 2) were parameterised from similar soils and improved pastures (buffel grass) from a long-term grazing trial data at Brigalow Research Station (Dalal et al., 2021). No parameterisation for climate change was completed within GRASP (e.g., only the climate files were different).

Table 2. Parameter values used in GRASP for Moura from the Brigalow Catchment Study for buffel grass pastures (Dalal et al., 2021).

GRASP Parameters (parameter number)	Parameter value
Potential regrowth per unit of grass basal cover (6)	8.0
Soil water index at which above-ground growth stops (149)	0.01
% N at which growth stops (101)	0.48
Maximum annual N uptake (kg N/ha) (99)	45.0
Green yield at which potential transpiration is 50% of potential ET (45)	1600
Transpiration efficiency kg/(ha.mm) @ 20hPa (7)	20.0
Detachment rate kg/(kg.day) warm season (128)	0.005
Detachment rate kg/(kg.day) cool season (130)	0.005

The GRASP model was run to generate monthly input files and a data cube for the Crop Livestock Enterprise Model (CLEM) containing the rainfall sequence and pasture production (monthly pasture growth) for each combination of the following factors:

- Grass basal area ranging from 1 to 6 (8 values)
- Land condition ranging from 0 to 11 (12 values)
- Stocking Rate ranging from 1 to 70 (23 values)

The total number of GRASP simulations for the historical climate was 2208. This model run was repeated for the same combination using the modified climate. These simulations show the effect of different grass basal areas, land conditions and stocking rates on pasture growth.

Grass basal area is important in the GRASP pasture model as it drives initial regrowth at the start of the growing season. It is also an important indicator of resource condition (both pasture and land condition).

Land condition determines the productivity of the land resource from the viewpoint of pasture and animal production as well as land management, with grazing management having a major impact on pasture condition. Table 3 shows the different land condition states.

Table 3. Percentage of perennial grasses in GRASP states and comparison with the ABCD condition framework (Source: Scanlan et al. 2014).

GRASP state[A]	**% perennial grasses**[A]	**ABCD condition**[BE]	**ECOGRAZE state**[C]	**General condition**[DE]
0	90	A	–	Very Good
1	88	A	–	Very Good
2	84	A	State I	Very Good
3	70	B	State I	Fair
4	50	B	–	Fair
5	32	C	State II	Fair
6	20	C	State II	Poor
7	15	C	–	Poor
8	10	C	–	Poor
9	5	D	–	Poor
10	2	D	–	Very Poor
11	1	D	–	Very Poor

[A] As used by McKeon et al. (2000). [B] As in Quirk and McIvor (2003). [C] As used in the ECOGRAZE trial – Ash et al. 2001, Ash et al. 2011). [D] These are general terms used to describe condition. [E] Land types vary in how heavy utilisation affects condition and pasture productivity. The A B C D system ranks condition in terms of relative pasture productivity. This approach provides a simple, general but qualitative calculation to discount pasture production from GRASP for condition A as used in GLM (MLA 2002) and FORAGE (Zhang and Carter 2018).

Livestock beef enterprise model

We employed the CLEM to develop a whole-of-farm model for our case study beef enterprise at Moura, Central Queensland. CLEM can test a range of management strategies in mixed crop and livestock systems with tracking impacts of finances, natural resources, and constraints such as labour at monthly time step. The modular (objected oriented) approach in CLEM provides a fully customisable and flexible set-up for complex whole farm simulations to be performed.

The case study beef enterprise is a production system solely consuming native pasture. We aim to study climate impacts on such a beef enterprise especially the differences in enterprise performances in the current and future climate, including environmental consequences. We then study the enterprise performances in a set of adaptation options for 2030 climate.

Conventionally, a beef enterprise model in CLEM realises native pasture growths at monthly time step through a pasture file obtained by an independent pasture simulation model. Such a conventional CLEM simulation allows only one direction impact from the pasture system to the livestock system but not vice versa. Moreover, CLEM currently cannot work directly with weather and climate data thus climate impacts on the beef enterprise would need to be represented in the realised pasture growths provided by the independent pasture simulation model.

Here, we develop advanced CLEM simulations for the case study beef enterprise allowing feedback interaction between the native pasture system and the livestock system. Such advanced CLEM feedback simulations would be able to study climate impacts on the studied beef enterprise in a meaningful way, allowing to see the dynamics of land conditions, grass basal areas (GBA), stocking rates and their effects on native pasture growth.

We employ the GRASP model developed for northern Australian grasses to simulate native pasture at the case study beef enterprise for a full range of possible land conditions, GBAs and stocking rates at the beef enterprise. Native pasture growth datacubes are developed for both historical climate and climate change in 2030. The datacubes allow setting up advanced feedback simulations in CLEM.

CLEM set up for the case study farm

The initial herd includes 3300 ruminants (Bos indicus) at different classes (Table 4). The initial number is set at a sustainable herd size of 3300 heads after consulting with the beef enterprise manager.

Table 4. Initial cohort in CLEM with different ruminant classes and associated details.

Ruminant class	Sex	Age (months)	Number of individuals	Weight (kg)	Standard deviation of weight (kg)
WeanerF	Female	9	450	178	62
WeanerM	Male	9	300	182	62
Female12	Female	22	450	403	41
Male12	Male	22	400	435	62
Heifers2Plus	Female	50	270	540	29
Male2Plus	Male	50	330	610	0
Cows	Female	60	860	535	0
Bulls (breeding sires)	Male	50	240	580	0

Native pasture datacubes

The GRASP model was run for both historical climate and climate change in 2030 to generate monthly pasture growths for each combination of the following factors:

Grass basal area ranging from 1 to 6 (8 values: 1, 1.5, 2, 2.5, 3, 4, 5, 6)

Land condition ranging from 0 to 11 (12 values) – 0 indicates the best land condition while 11 is the worst.

Stocking rate ranging from 1 to 70 (23 values: 1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70)

The total number of GRASP simulations for the historical climate was 2208, being equivalent to 8 x 12 x 23 factorial combinations of grass basal area x land condition x stocking rate. The same number of GRASP model runs for the same factorial combinations was conducted using the modified climate. Note that a stack input file for the GRASP model was generated including all the model parameters for the case study together with the factorial combinations. These 2208 factorial combinations were automatically constructed using a Python code created by Chris Stokes (pers com.). The factorial simulated monthly pasture growths were used to construct two datacubes for historical climate and climate change. To do this, a Matlab code was developed to read and process the factorial GRASP simulation outputs, connect to a database tool (DB Browser), and put the processed factorial outputs to a database file (Table 5).

Table 5. Format of the developed datacubes for native pasture growths at the Moura case study.

Region	Soil	GrassBA	LandCon	StkRate	Year	Month	Growth	SoilLoss	RunOff	Rainfall	Cover	TreeBA
Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
0	1	1.0	0	1	1975	1	837.6	115.0	4.0	85.0	0.0	4.0
0	1	1.0	0	1	1975	2	94.1	83.0	3.0	73.0	0.0	4.0
0	1	1.0	0	1	1975	3	564.7	6.0	0.0	35.0	0.0	4.0
0	1	1.0	0	1	1975	4	311.6	0.0	0.0	27.0	0.0	4.0
0	1	1.0	0	1	1975	5	91.5	0.0	0.0	0.0	0.0	4.0
0	1	1.0	0	1	1975	6	11.0	117.0	4.0	65.0	0.0	4.0
0	1	1.0	0	1	1975	7	34.9	11.0	0.0	19.0	0.0	4.0
0	1	1.0	0	1	1975	8	26.1	1.0	0.0	24.0	0.0	4.0
0	1	1.0	0	1	1975	9	46.6	0.0	0.0	16.0	0.0	4.0
0	1	1.0	0	1	1975	10	85.3	353.0	13.0	171.0	0.0	4.0
0	1	1.0	0	1	1975	11	445.8	184.0	7.0	101.0	0.0	4.0
0	1	1.0	0	1	1975	12	738.6	400.0	15.0	168.0	0.0	4.0
0	1	1.0	0	1	1976	1	1712.5	7.0	0.0	30.0	0.0	4.0
0	1	1.0	0	1	1976	2	845.6	11.0	0.0	66.0	0.0	4.0
0	1	1.0	0	1	1976	3	736.4	0.0	0.0	27.0	0.0	4.0
0	1	1.0	0	1	1976	4	40.8	8.0	0.0	24.0	0.0	4.0
0	1	1.0	0	1	1976	5	73.7	0.0	0.0	8.0	0.0	4.0
0	1	1.0	0	1	1976	6	9.4	25.0	1.0	27.0	0.0	4.0

These datacubes (database files) were then read by a CLEM component – FileSQLitePasture.

Manage pasture in CLEM

Two relationships were deployed in a CLEM activity (PastureActivityManage) to establish the change in land condition and grass basal area according to the utilization percentage (Figures A4&5, respectively). These relationships also allow us to set initial land condition and grass basal area as well as their ranges. At each time step with the utilization percentage, CLEM uses these two relationships to determine the land condition and grass basal area. At a certain stocking rate in CLEM, the determined land condition and grass basal area allow to receive corresponding monthly native pasture growth from the datacube. By this way, feedback of livestock system on pasture system including land condition and, grass basal area can be achieved. The native pasture growth is then stored in a GrazeFoodStore, ready for grazing.

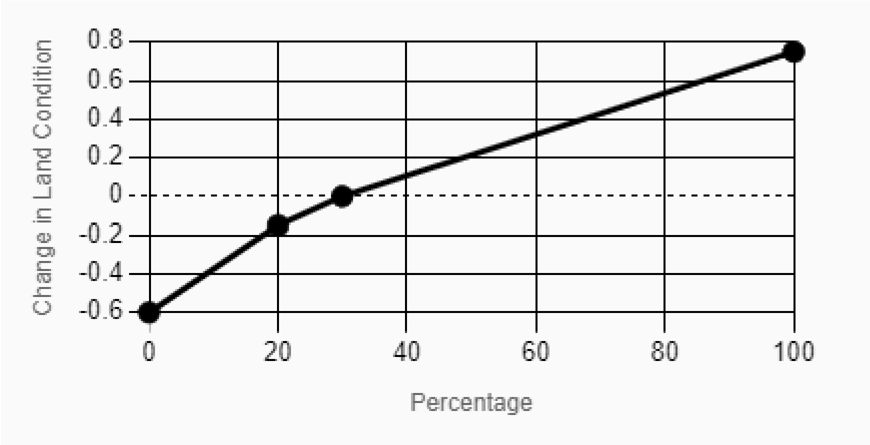


Figure 4. Change in land condition as a function of utilization percentage.

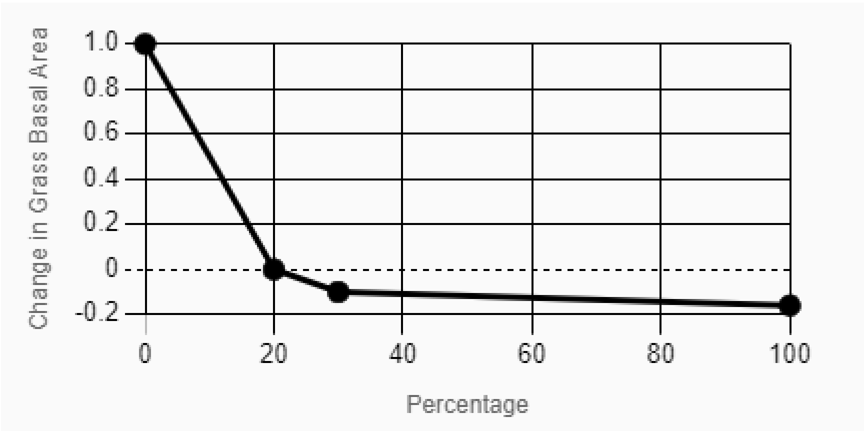


Figure 5. Change in grass basal area as a function of utilization percentage.

Manage herd in CLEM

All ruminants are moved to the paddock and graze the native pasture available in the GrazeFoodStore. Controlled mating is set at annual interval starting in December for a 3 months period. Weaning rule is set based on age (9 months) or weight (205 kg) at annual interval starting in April. Managing the numbers happens once a year starting in August at mustering. In addition to this, a predictive seasonal destocking operation is performed in May to avoid overgrazing which can damage land condition and have a shortage of feed leading to cattle mortality. The aim of this predictive destocking operation is to make the simulation replicate what can happen in a real farming situation. Greenhouse gases levels are reported in a GreenhouseGasesLedger in CO2e

Cost of production

Production costs of different treatments and classes of cattle are consulted with the enterprise owner and given in Table 6.

Table 6. Costs of production including herd and husbandry costs, and pregnancy testing (AUD/head)

Treatment	Weaners male & female	Heifers 1-2 yr	Cows 2-3 yr	Cows 3 yr+	Bulls	Steers 1-2 yr	Steers 2-3 yr	Steers 3 yr+
NLIS tag	3							
Vaccines (7in1)	5							
Three day vaccine					35			
Pestiguard		10			5 (1/3)			
Vibro		5			5 (1/3)			
Bovillis					5 (1/3)			
Drench	5							
Tick control					10			
Tick fever vaccine		10	10	10	10	10	10	10
Others (trisulphuran, bucadil)	2							
Pregnancy testing		5	5	5				

Adaptation options and modelling procedures

A meeting of the reference group was held on 26 February 2021 to identify likely adaptation options relevant to Central Queensland. As a result, four adaptation options were selected to be modelled (Table 7).

Table 7. Central Queensland modelled adaptation options based on improved feedbase, management and genetics.

Adaptation measure	Modelling approach
Improved pastures	Increasing grass basal area (GBA) by 2% e.g. from the current 3% to 5%
Improved reproduction	The relevant coefficients for the equation relating animal liveweight to conception rates are set to achieve an increase in the average weaning rates by 5%
Improved growth rate	The growth conversion efficiency coefficients adjusted to improve a liveweight growth improvement of 10%
Improved rumen function	Facilitating better digestion of low-quality pasture: monthly decline in digestibility of 8% used instead of 10% decay rate, lower limit on digestibility is raised by 3% e.g. from 43% to 46% digestibility.

Improved pasture

The effect of increased pasture yield from oversowing a native pasture with a legume was simulated by increasing the initial, minimum and maximum perennial grass basal area by 2 percentage points within the GRASP pasture growth model (Table 8), which increases forage growth by 20%. This is consistent with experimental data which shows augmentation of native pasture with legumes can increase pasture biomass by 10-30% (McIvor and Gardener, 1995). The monthly nitrogen decay rate was reduced from 35% per month to 10% per month to simulate the year-round higher protein content of legume-augmented pastures. The dry matter digestibility decay rate was reduced from 10% to 7%. The land condition index was kept at 6 (moderate land condition at the enterprise). The maximum breeder numbers that could be carried were increased in line with the proportionate increase in forage production (typically resulting in herd size being 20% greater than for the baseline scenario).

Table 8. Parameterisation for baseline and improved pasture. We rerun the GRASP model to update the grass growth datacubes (both historical and 2030 climate) for larger values of GBA (up to 8).

Parameter		Baseline pasture	Improved pasture
Grass basal area (GBA)	Initial	3	5
	Minimum	1	3
	Maximum	6	8
Monthly N loss (%)		35	10
Monthly dry matter digestibility (DMD) loss (%)		10	7
Land condition index		6	6

Improved reproduction through genetic gain

The relevant coefficients for the equation relating animal liveweight (body condition) to conception rates were set to achieve an increase in the average weaning rate of 5 percentage points. This permitted higher rates of conception to occur at the same body condition score (Figure 6). This level of simulated increase in reproductive performance is considered available (Johnston et al. 2014).

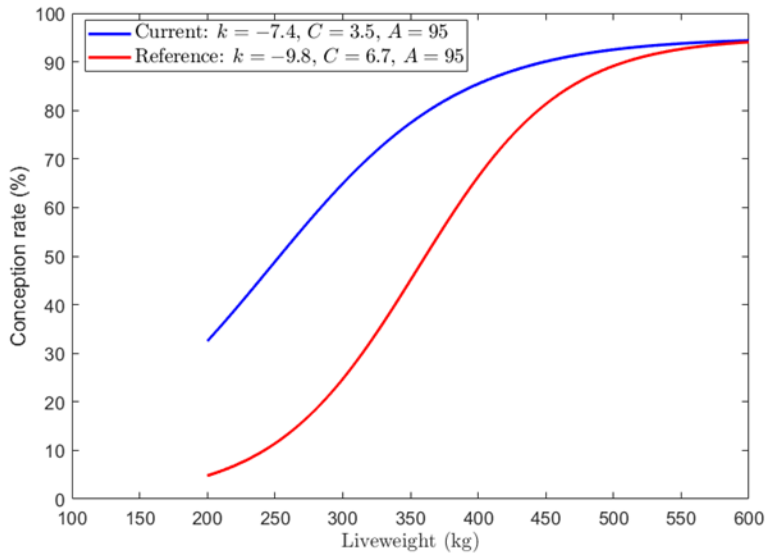


Figure 6. Baseline conception curve (red line) and improved conception curve (blue line) and the associated parameters.

$$\text{Conception rate (\%)} = \frac{A}{1 + \text{Exp}\left(k * \frac{\text{cow wt actual}}{\text{cow reference wt}} + C\right)}$$

A = Asymptote maximum conception rate

k = Coefficient for shape of the curve

C = Constant

Improved growth rate (growth efficiency through genetic gain)

The Feeding Standards of Australia (CSIRO, 2007) growth conversion efficiency coefficients were adjusted to achieve a liveweight growth improvement of approximately 10%. Burrow and Rudder (1991) have demonstrated that efficiencies of this magnitude can be achieved through genetic selection.

Improved rumen function to more effectively metabolise ingested pasture

This scenario assumed an improvement in rumen function through an additive or by modifying rumen function to facilitate better digestion of low-quality pasture. This was achieved by reducing the rate at which dry matter digestibility declined each month following pasture senescence (e.g., a monthly decline in digestibility per month of 8% was used instead of a 10% decay rate) and the lower limit on digestibility was raised by three percentage points (e.g., from 43% to 46% digestibility). This scenario led to increased feed intake in response to higher rumen throughput. Achieving this level of improvement in rumen function appears possible (McSweeney et al. 1999) and is justified in the simulations through practical limitations remain.

Results

Impacts of 2030 climate

Climate change impacts might be different depending on the initial condition of the studied object. We thus studied performances of the beef enterprise in the historical climate and the 2030 climate with a scenario of initial setting. While the current land condition (LC) at the beef enterprise is close to a moderate condition – land condition index is 6 – we also simulated the climate change impacts at good initial land condition (land condition index is 1) and poor initial land condition (land condition index is 10).

Pasture growth

We studied the impacts of the 2030 climate on pasture growth in two modelling settings:

Setting 1. Solely pasture system using the GRASP model at the current moderate initial land condition.

Setting 2. Interactive pasture system and livestock system using the developed pasture datacubes in CLEM (feedback simulation). Three initial land conditions were simulated, i.e., good, moderate and poor.

Setting 1

Historical and 2030 rainfall and modelled pasture growth were generated for annual, seasonal and monthly timescales (Figures 7-9).

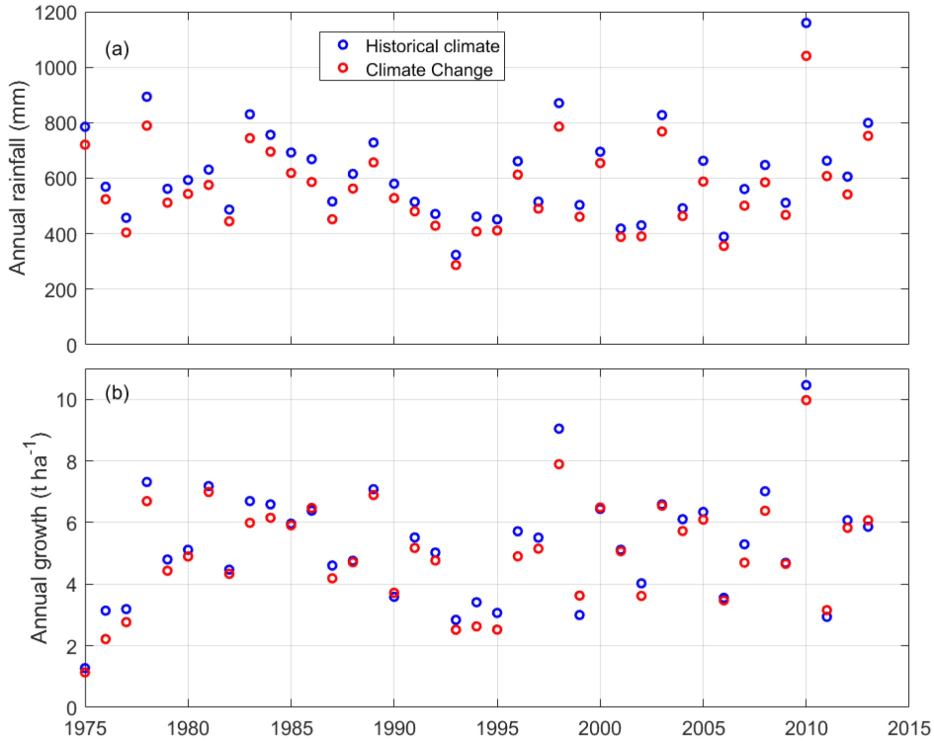
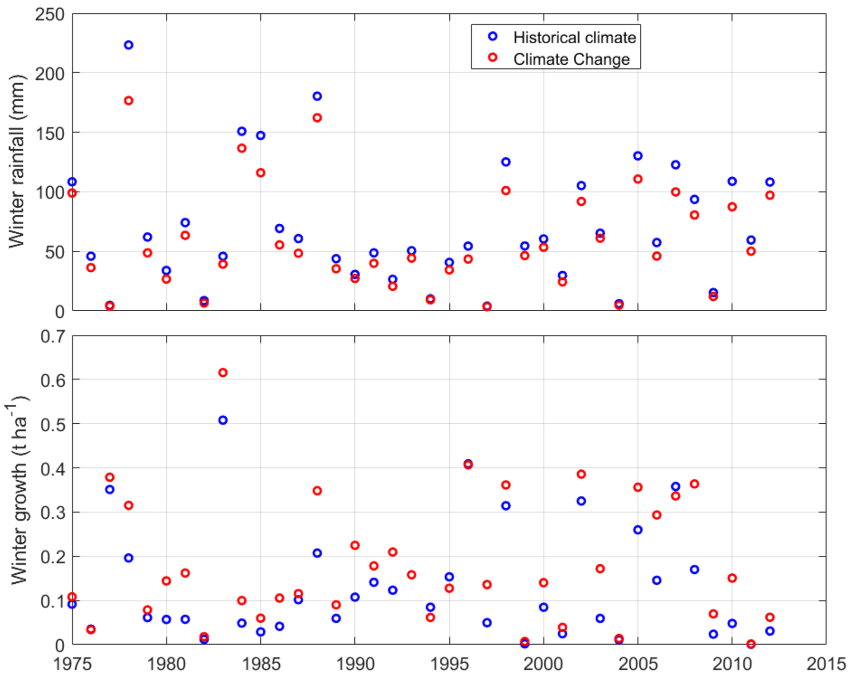


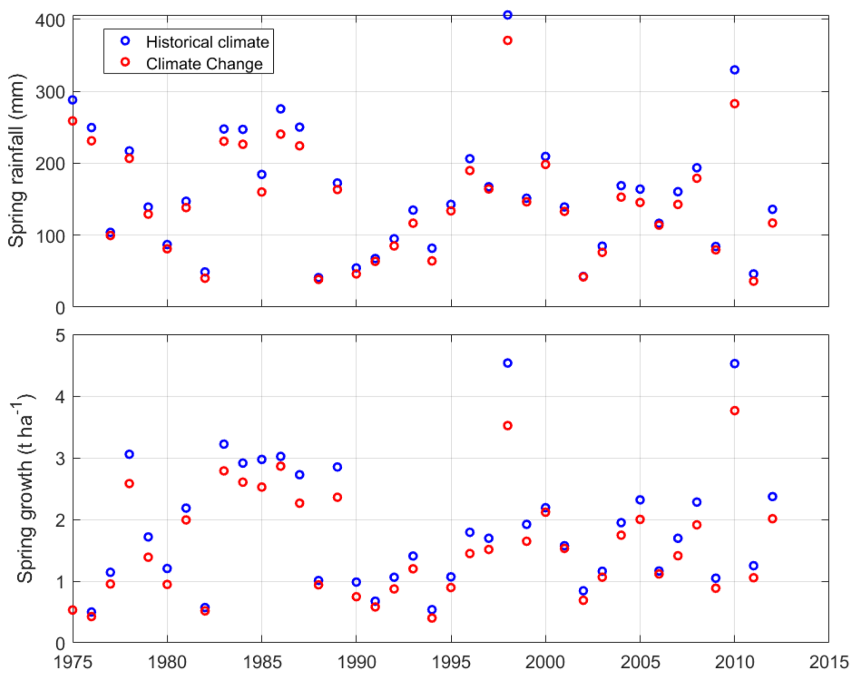
Figure 7. Annual differences in rainfall (a) and pasture growth (b) between historical (blue) and 2030 (red) climate.

Annual growth was generally lower for 2030 compared to historical.

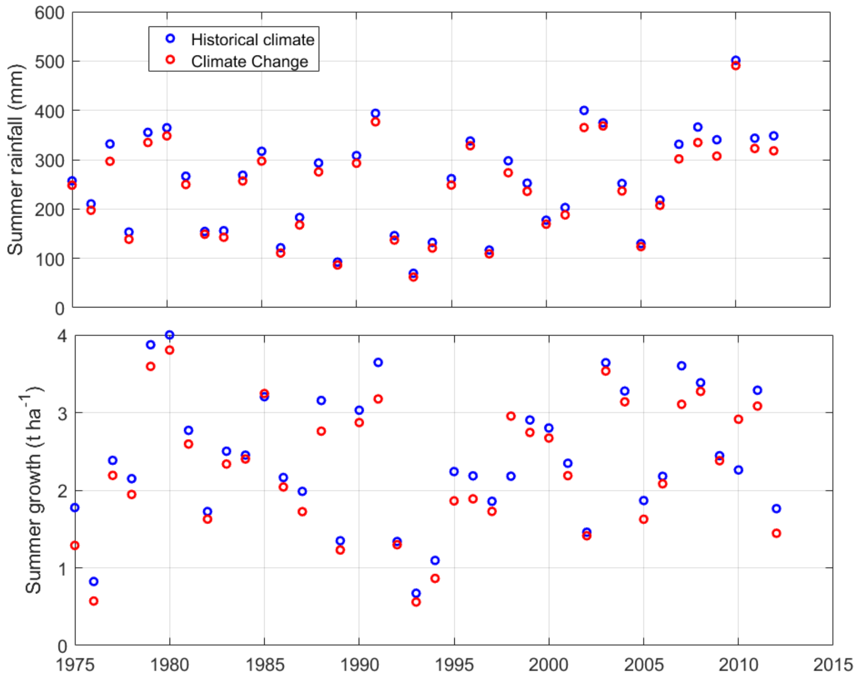
Winter



Spring



Summer



Autumn

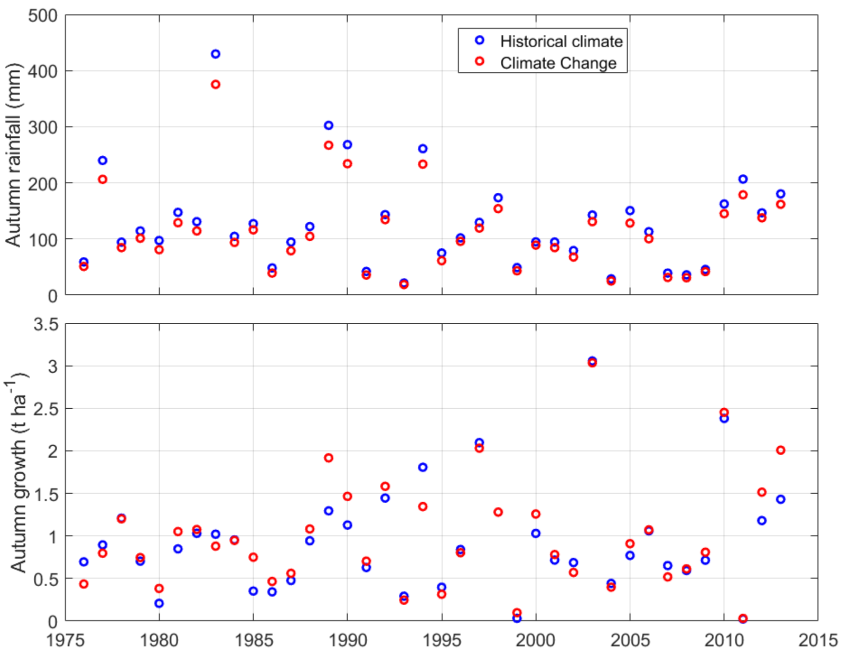


Figure 8. Seasonal differences in rainfall (top panels) and pasture growth (bottom panels) between historical (blue) and 2030 (red) climate.

Summer and spring growth will be lower in 2030 compared to historical due to a reduction in seasonal rainfall. Autumn and winter growth will be higher in 2030 compared to historical owing to higher temperatures not limiting growth causing a longer growing season. The higher growth in winter for

2030 will not be sufficient to outweigh the lower growth in summer and spring – shown by lower annual growth in 2030 compared to historical.

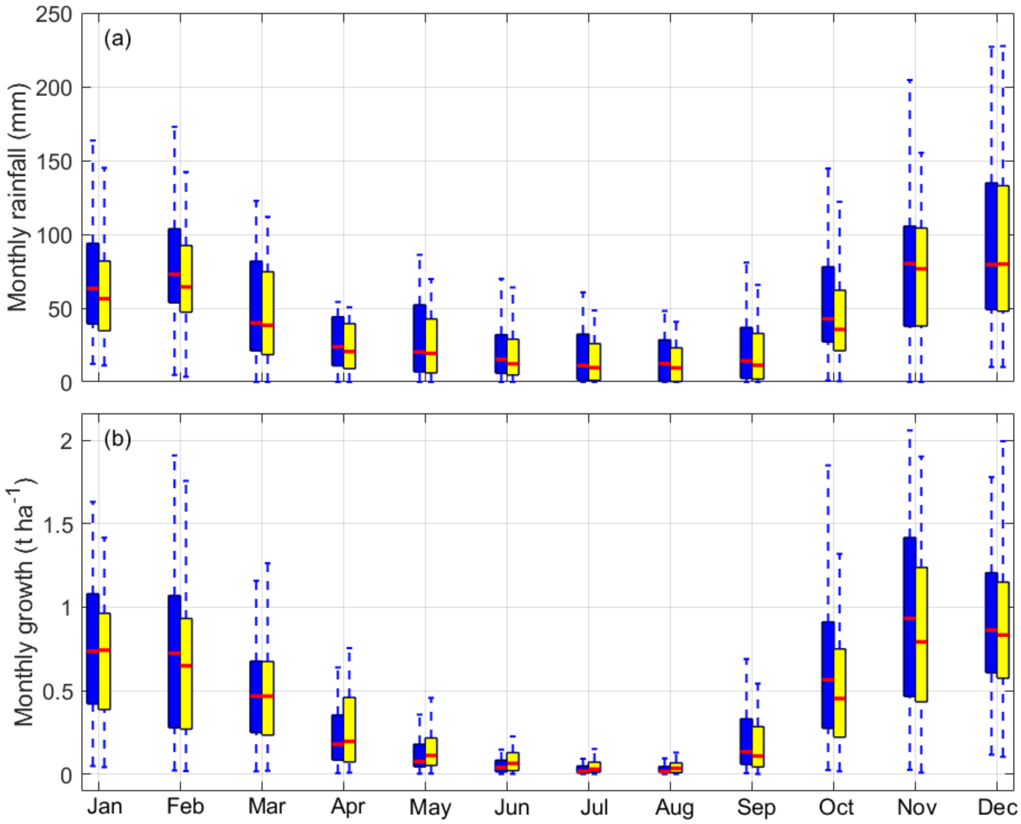


Figure 9. Monthly differences in rainfall (a) and pasture growth (b) between historical (blue) and 2030 (yellow) climates.

The monthly analysis of growth confirms the annual and seasonal output where higher growth during winter and autumn in 2030 is insufficient to outweigh the detrimental impacts of higher temperature and lower rainfall in spring and summer on annual growth.

Setting 2

Table 9. Annual pasture growth in the historical and 2030 climate with three initial land conditions. The initial grass basal area (GBA) was set at 3% in the three cases.

Initial land condition	Initial Land condition index	Average annual pasture growth (kg ha^{-1})		Standard deviation (kg ha^{-1})	
		Historical climate	Climate change	Historical climate	Climate change
Good (G)	1	4047	3296	1589	1558
Moderate (M)	6	3451	3126	1433	1427
Poor (P)	10	2669	2485	1184	1168

- Historical climate was 23, 10, 7% higher than 2030 climate for G, M, P land conditions, respectively.
- Good initial land condition was 52% and 33% higher than poor initial land condition for historical and 2030 climate, respectively.
- Historical climate showed greater variability in annual growth than 2030 climate.

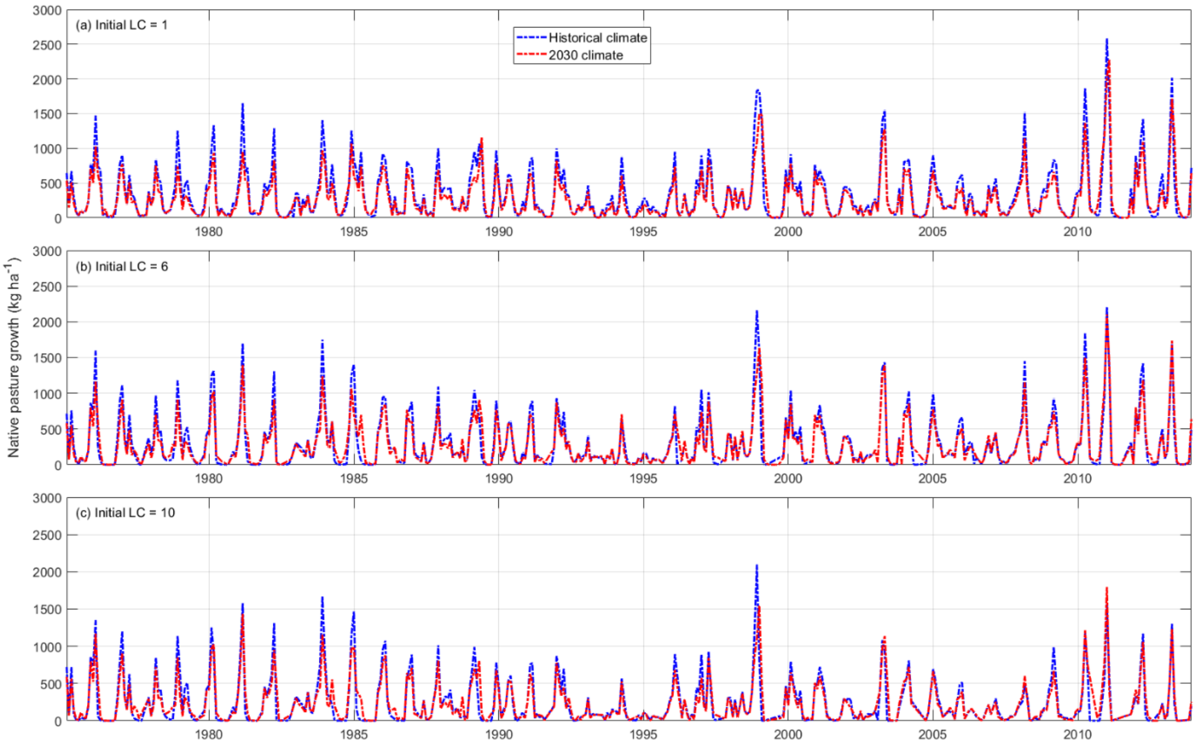


Figure 10a. Native pasture growth per ha in historical climate and changing climate at three initial land conditions (LCs) i.e. good (1), moderate (6) and poor (10). The initial grass basal area (GBA) was set at 3% in the three cases.

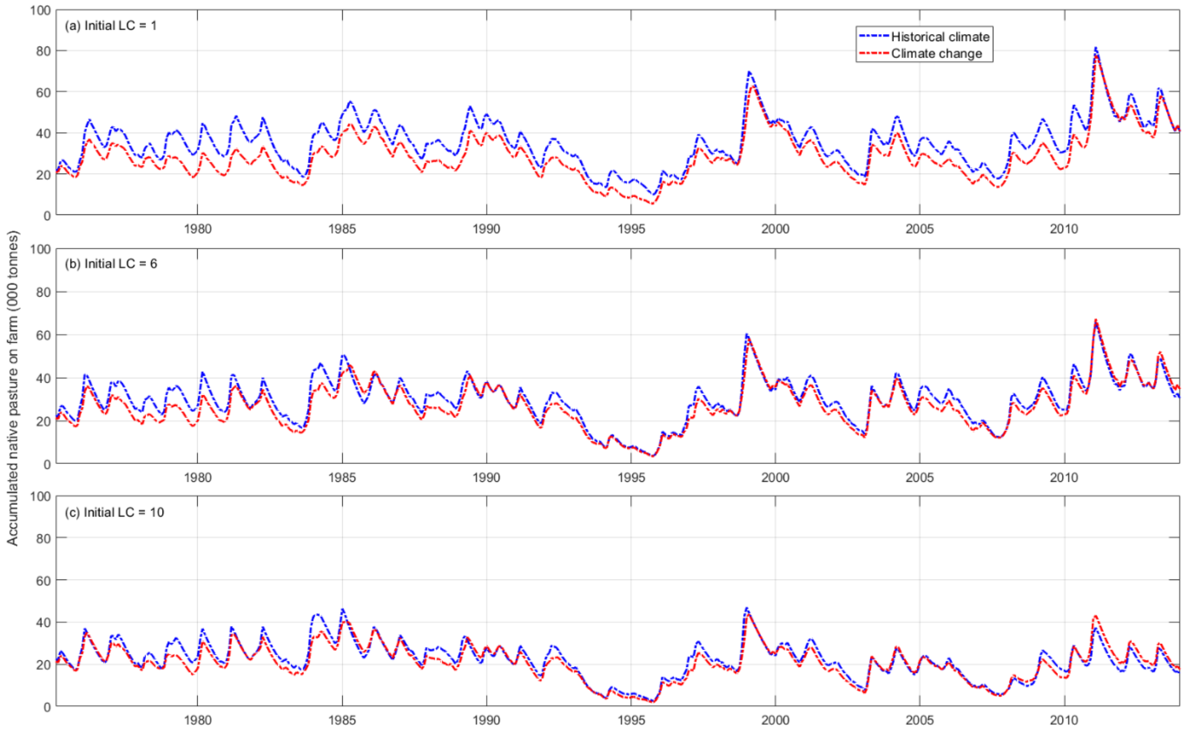


Figure 10b. Accumulated native pasture on farm in historical climate and changing climate at three initial land conditions (LCs) i.e. good (1; top), moderate (6; middle) and poor (10; bottom). The initial GBA was set at 3% in the three cases.

Seasonal (Table 10, Fig 11)

- The historical climate has higher growth in autumn, summer and spring than the 2030 climate as a direct result of rainfall reduction in 2030.
- Despite reduced rainfall also occurring in winter of the 2030 climate, higher growth in the 2030 climate compared to the historical climate can be achieved owing to increasing winter temperature not limiting pasture growth.

Table 10. Seasonal pasture growths for the historical and 2030 climates at three initial land conditions i.e. good, moderate and poor. The initial GBA was set at 3% in the three cases.

Initial land condition	Initial land condition index	Seasonal average (kg ha^{-1})							
		Historical climate				Climate change			
		Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Good	1	1124	183	998	1772	908	203	802	1439
Moderate	6	854	123	879	1618	811	166	767	1418
Poor	10	617	81	683	1298	624	114	593	1167

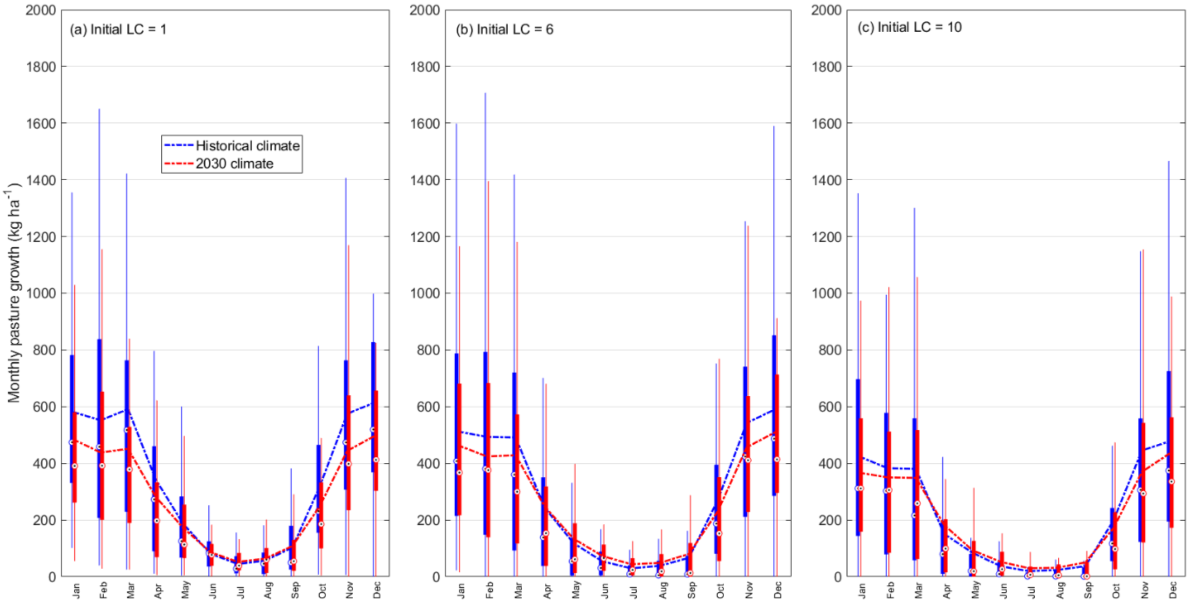


Figure 11. Monthly pasture growth at the beef enterprise for historical and 2030 climate change at three initial land conditions (LCs) i.e. good (1; left), moderate (6; middle) and poor (10; right). The initial GBA was set at 3% in all three cases. Monthly averages (dotted lines) and box plots of pasture growths are presented – blue indicates historical climate while red indicates climate change.

Animal numbers (Table 11, Fig 12)

- The historical climate has higher animal numbers than the 2030 climate in all initial land conditions, indicating that the 2030 climate will see a reduction in the sustainable herd size.
- Better initial land conditions allow greater and more stable animal numbers.
- Even with good land condition, animal number is more vulnerable to drought in 2030 climate (Fig A12a; top panel). For example, during the extreme droughts such as the Millennium drought, animal number is stable in the historical climate but reduced notably in the 2030 climate.

Table 11. Animal number of the beef enterprise for historical and 2030 climate at three initial land conditions, i.e., good, moderate and poor. The initial GBA was set at 3% in the three cases.

Initial land condition	Initial Land condition index	Average animal number		Standard deviation	
		Historical climate	Climate change	Historical climate	Climate change
Good	1	3307	2824	247	296
Moderate	6	3111	2744	346	322
Poor	10	2903	2580	394	397

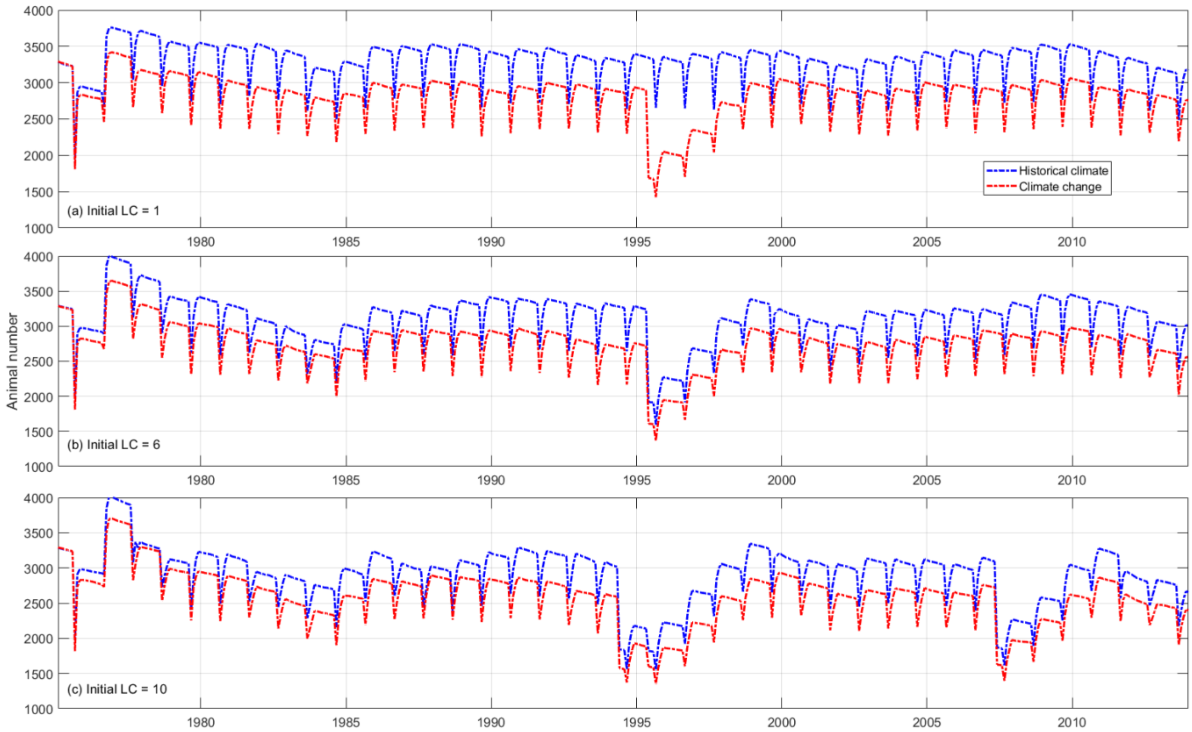


Figure 12. Total animal numbers in herds for the historical climate and 2030 climate at three initial land conditions (LCs) i.e. good (1; top), moderate (6; middle) and poor (10; bottom). The initial GBA was set at 3% in the three cases.

Comparison between Setting 1 and Setting 2

- Winter pasture growth in the 2030 climate is consistently higher than that in the historical climate in both settings.
- With the interaction of livestock system in the Setting 2, we show that there will be a reduction in annual pasture growth of the beef enterprise in all land conditions in the 2030 climate, as well as the pasture growth improvements of better land conditions.

Livestock

Annual liveweight gain (Table 12)

- The 2030 climate had slightly higher annual liveweight gain of steers than that in the historical climate for good, moderate and poor initial land conditions owing to better winter pasture growth.

Table 12. Annual weight gains of the steers (males up to 24 months) for the historical climate and 2030 climate at three initial land conditions, i.e., good, moderate and poor. The initial GBA was set at 3% in the three cases.

Initial land condition	Initial Land condition index	Average annual weight gain (kg)	
		Historical climate	Climate change
Good	1	197	201
Moderate	6	184	191
Poor	10	172	183

Seasonal liveweight gain (Table 13)

- The 2030 climate has higher liveweight gain of steers in winter than that in the historical climate for good, moderate and poor initial land conditions. Meanwhile, lightweight gains of steers in other seasons are equivalent in the historical and 2030 climates, indicating that the annual pasture growth reduction in the 2030 climate will not influence the development of steers.

Table 13. Seasonal weight gains of the steers (males up to 24 months) for the historical climate and 2030 climate at three initial land conditions i.e. good, moderate and poor. The initial GBA was set at 3% in the three cases.

Initial land condition	Initial land condition index	Seasonal average weight gain (kg)							
		Historical climate				Climate change			
		Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Good	1	65	33	40	60	65	37	41	59
Moderate	6	62	30	34	58	62	36	36	58
Poor	10	59	27	30	57	61	34	32	57

Livestock emissions (Table 14, Fig 13)

- Monthly emissions were lower in the 2030 climate for good, moderate and poor initial land conditions owing to smaller herd sizes.

Table 14. Monthly emissions of the beef enterprise in the historical climate and 2030 climate at three initial land conditions i.e. good, moderate and poor. The initial GBA was set at 3% in all three cases.

Initial land condition	Initial land condition index	Monthly average (tCO2e)	
		Historical climate	Climate change
Good	1	12.53	10.71
Moderate	6	11.42	10.24
Poor	10	10.38	9.46

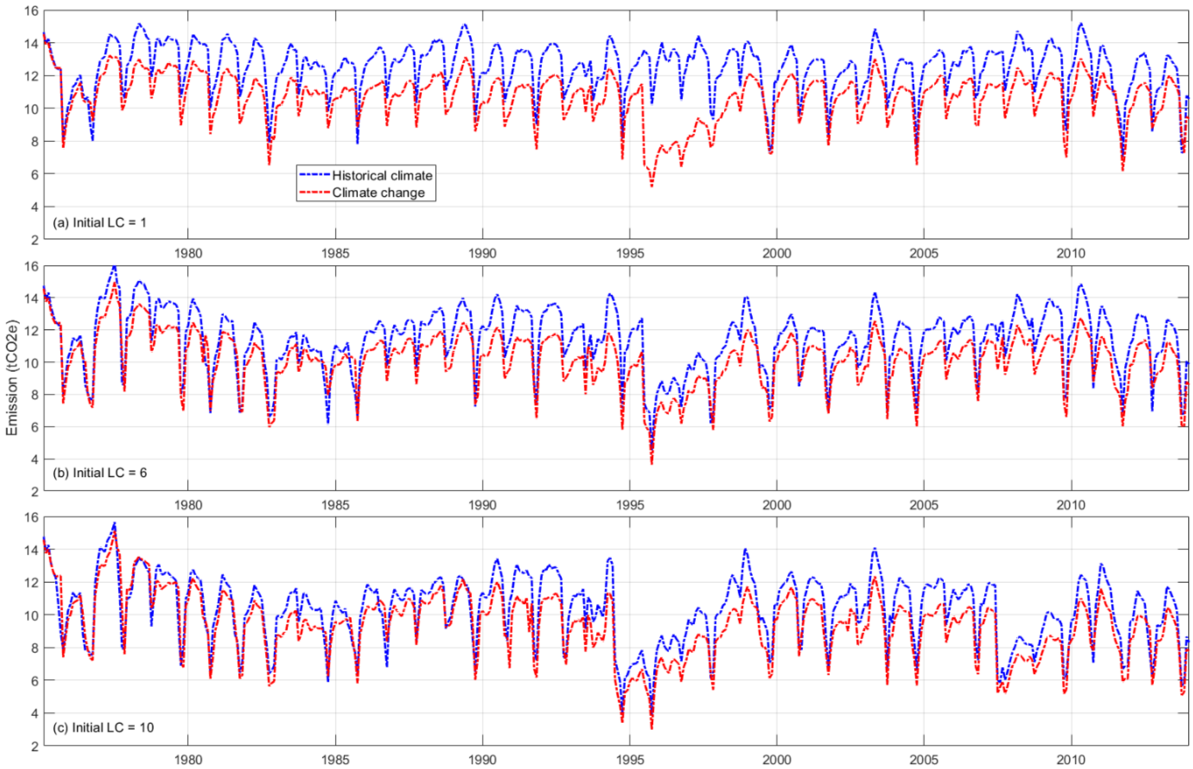


Figure 13: Total emissions of the beef enterprise in tCO2e for historical climate and changing climate at three initial land conditions (LCs) i.e. good (1; top), moderate (6; middle) and poor (10; poor). The initial GBA was set at 3% in all three cases.

Profit (Table 15, Fig 14)

- The 2030 climate average annual profit was lower – $105, 47, and 18K per year, respectively – than the historical climate for good, moderate, and poor initial land conditions.

Table 15. Average annual profit of the beef enterprise in the historical and 2030 climates at three initial land conditions, i.e., good, moderate and poor. The initial GBA was set at 3% in all three cases.

Initial land condition	Initial Land condition index	Average annual profit of the beef enterprise (AUDk)	
		Historical climate	Climate change
Good	1	870	765
Moderate	6	741	694
Poor	10	635	617

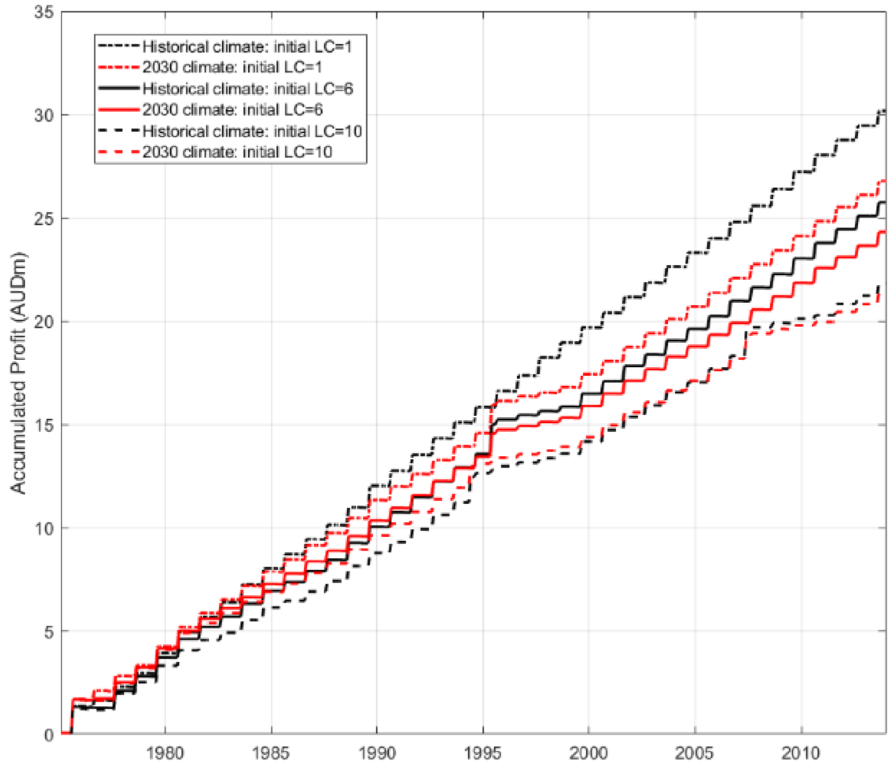


Figure 14. Accumulated profits of the beef enterprise in historical and 2030 climate at three initial land conditions (LCs), i.e., good (1), moderate (6) and poor (10). The initial GBA was set at 3% in the three cases.

Land condition and grass basal area

- Poor initial land condition did not recover under these pasture and herd management conditions due to the reducing trend of grass basal area. The herd size thus needs to be reduced to improve land conditions and grass basal area in long term.
- In contrast, G&M initial land conditions allow the land condition could be improved over time owing to increasing trends of grass basal area.
- We show here the importance of a sustainable initial land condition and herd size in adapting to the changing climate, avoiding deterioration of the ecological condition including land condition and grass basal area.

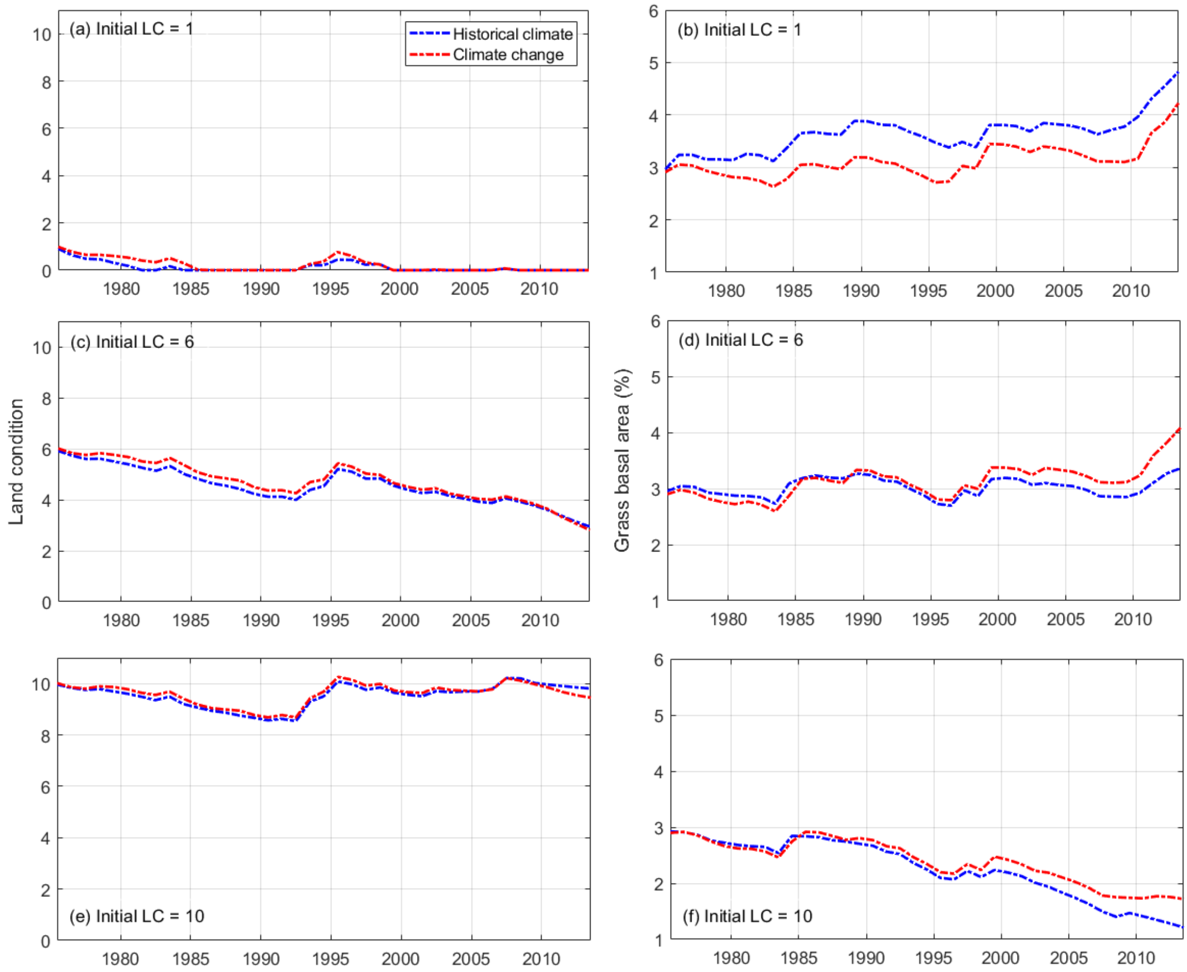


Figure 15: Land condition (left panels) and grass basal area dynamics (right panels) at the beef enterprise for historical climate and changing climate at three initial land conditions (LCs,) i.e., good (1; top panels), moderate (6; middle panels) and poor (10; bottom panels). The initial GBA was set at 3% in all three cases.

Results summary for the four adaptation options

- In terms of profit (Fig. 16), improved pasture by sowing legume crops shows the best performance – average annual profit is greater ($256k per year) than that of the baseline historical climate. Improved rumen function is an option that can maintain the current baseline profit level. Improved conception to achieve better weaning rate and improved growth rate are not options to maintain or improve the profit.
- Improved pasture can also allow to increase sustainable herd size i.e. without deteriorating land condition in the long term (Fig. 17a) while other three adaptation options show reductions in sustainable herd size. This results in a similar pattern of the costs of production (Fig. 17b).
- Improved pasture and rumen functions are the two options that can improve and maintain, respectively, the economic efficiency of the available resources represented in gross margin per AE (Fig. 17c) and gross margin per ha (Fig. 18a).
- Improved pasture and rumen functions can also improve and maintain, respectively, the annual enterprise beef production (Fig. 17d).

- The four options show similar or lower levels of emission intensity compared to that under the baseline historical climate (Fig. 17e).
- Improved pasture, growth rate and rumen function can achieve better monthly live weight gains in the 2030 climate than that of the baseline enterprise in the historical climate (Fig. 18b). Without adaptation, the enterprise can still maintain or improve the average live weight gain (compared to that of the historical period) owing to better pasture growth in winter.

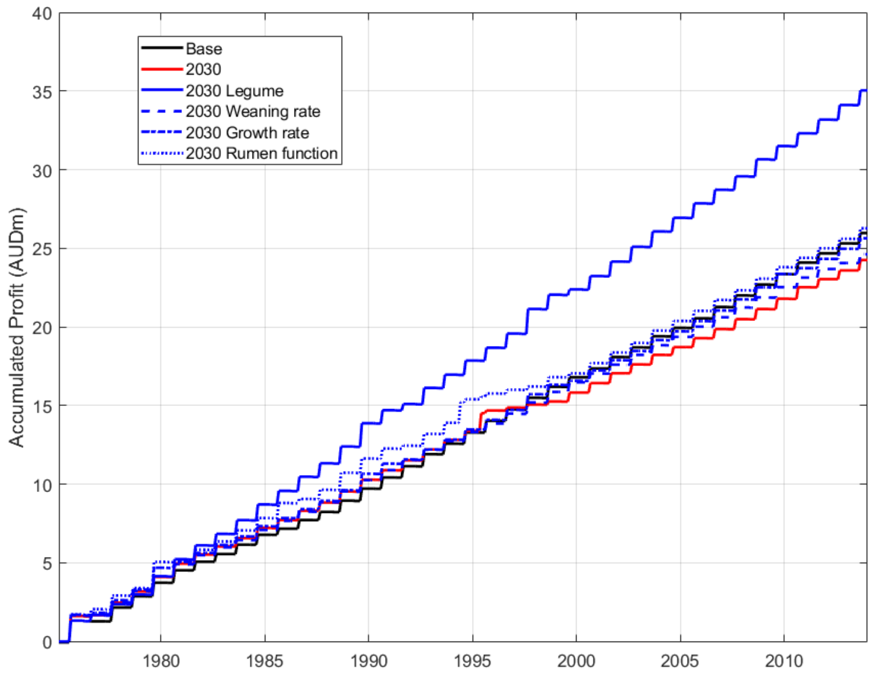


Figure 16: Accumulated profits in the historical and 2030 climate, and in the four adaptation options. The initial land condition was kept at 6 (i.e., moderate condition) in all these simulations.

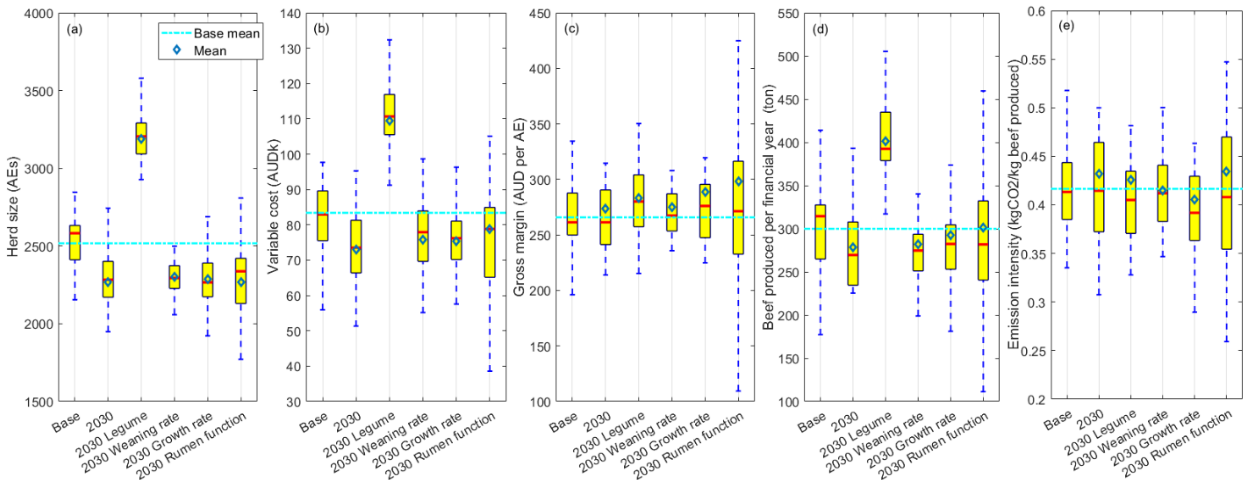


Figure 17: Combined results of five performance indicators in the historical and 2030 climates, and in the four adaptation options.

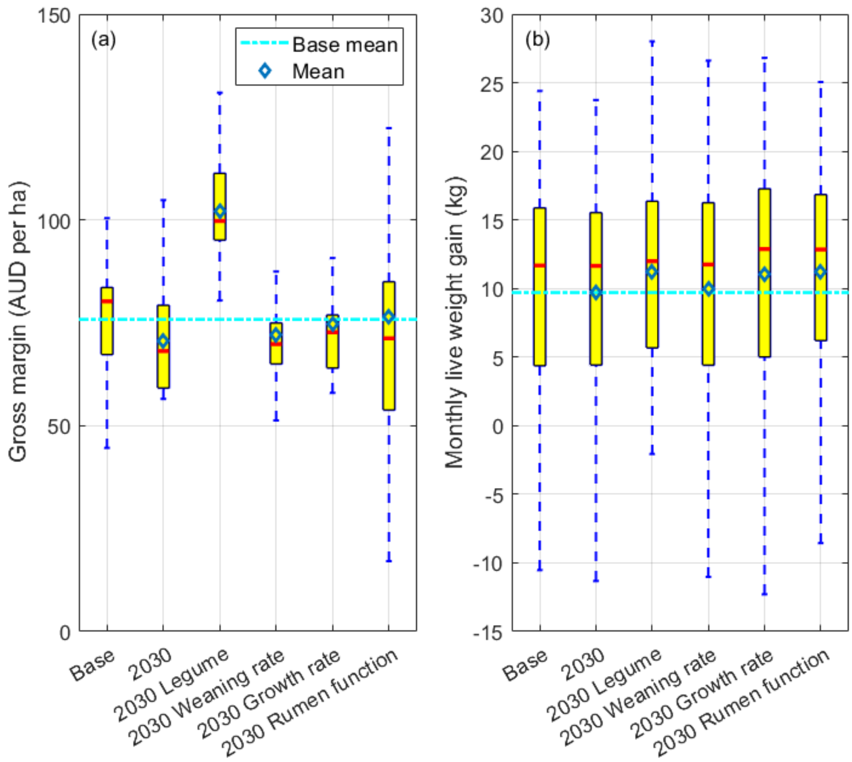


Figure 18. Combined results of gross margin per ha (left) and monthly live weight gain (kg/head; right) of one year age group (12-24 months) in the historical and 2030 climates, and in the four adaptation options.

It should be noted that the gross margin per AE in the present study is more than $250 which is higher than the regional averages in south-east and northern Queensland (Holmes 2011, Ash et al. 2015). Gross margin estimation depends on how we consider the production costs which might include labour and overhead costs being not considered here.

We can anticipate the greater benefits by combining improved pasture with other adaptation options.

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8.4 Social research

Questionnaire results

The following stacked bar charts represent the distribution of responses per Nexus reference group for each statement they rated in the questionnaire (strongly disagree-strongly agree) in relation to various types of human and social capital that may be enable the implementation of each of the Nexus adaptation pathways. The responses for each statement were grouped into three main categories- ‘more capacity’ (represents the agree/strongly agree responses), ‘neutral’ (represents the neutral responses) and ‘less capacity’ (represents the disagree/strongly disagree responses).

The five types of human capital were:
1. Knowledge and skills
2. Farm workforce
3. Decision making power to make choices
4. Self-responsibility (accountability for your choices)
5. Self-efficacy

The give types of social capital were:
1. Government and industry policy as an enabling factor for adaptation
2. Access to adequate regional services and programs as an enabling factor for adaptation
3. Capacity of regional service providers to develop options (possibilities) for implementing the Nexus adaptation pathways
4. Being active mentors to peers regarding the Nexus adaptation pathways
5. Social networks as learning opportunities about the Nexus adaptation pathways (general focus of the pathways – adapt/diversity and grow/mitigating GHG).

Please note the following:

- a copy of the producer and adviser questionnaire can be viewed below
- The neutral responses received particularly from the Northern Victorian reference group is partly explained by the advisers giving the Nexus team feedback that it was often difficult to rate the statements on behalf of the client base (which sometimes involves servicing up to 200 producer clients). The neural option was thus the best response when there was either uncertainty about the statement, or it was difficult to represent the diversity of an adviser’s client base.
- The response distributions for the rated statements involving physical, financial and natural capitals can be made available from the social researcher by request. Human and social capitals were the focus for this report in alignment with the milestone and final reporting requirements.

Acronyms:

NV – Northern Victoria reference group

EG – East Gippsland reference group

NNSW – Northern NSW reference group

HUMAN CAPITAL

Knowledge and skills – key results

Across the three reference groups (Northern Victoria, East Gippsland and Northern NSW), the general response was that reference group members or their client base have the skills and knowledge to implement the 'adapt' pathways (Figure 1). However, the capacity to draw on skills and knowledge declined when assessing their own or their client's skills and knowledge when it came to implementing the 'diversify and grow' and 'towards carbon neutral' pathways.

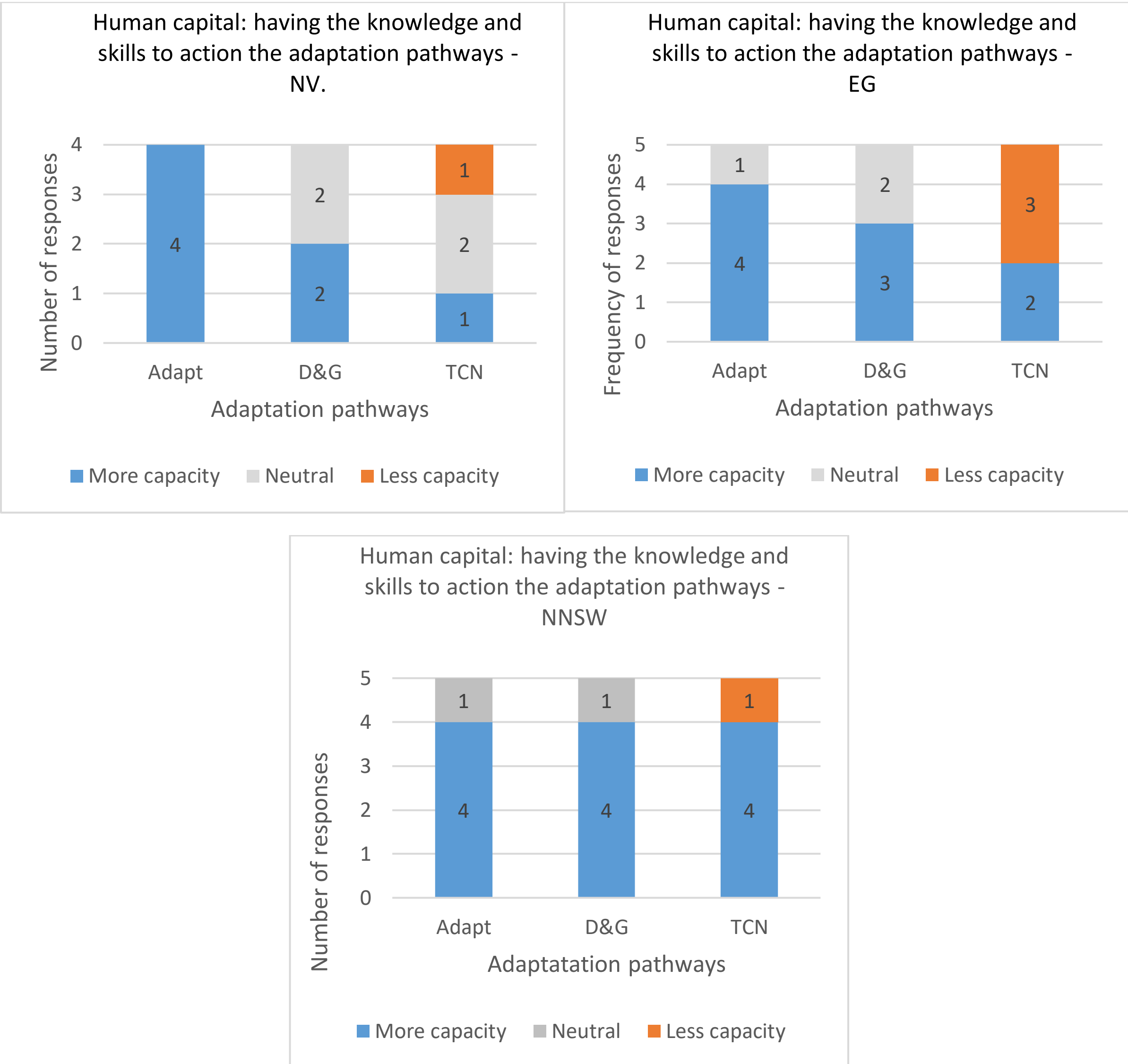

Figure 1. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to having the knowledge and skills to action the Nexus adaptation pathways.

The exception to this trend was the responses from the NNSW reference group. Members consistently assessed that they have the skills and knowledge (more capacity to adapt) to implement all three Nexus adaptation pathways. This is explained by the reference group members noting that they have recently participated in various short courses in carbon accounting and are using various apps to calculate their carbon footprint. Some reference group producers are also currently in a growth/expansion stage of their livestock business or have been through this business cycle so are experienced in thinking about diversifying and growing their enterprise.

Farm workforce– key results

There was a mixed response across the three reference groups when it comes to assessing the accessibility/availability of a farm workforce to implement the Nexus adaptation pathways (Figure 2). NV reference group indicated there was some adaptive capacity in terms of having the workforce to enable the implementation of the 'adapt' and 'diversify and grow' pathway. However all reference group members took a neutral response to assessing workforce for the 'towards carbon neutral' pathway, because people were not certain what workforce requirements are needed to transition towards carbon neutral agriculture, as well as not being able to assess this capacity for a diverse client base. The EG reference group indicated that their adaptative capacity was constrained by the unavailability/inaccessibility of a farm workforce to implement the three adaptation pathways. At the same time, there were some producers who indicated that had the farm workforce they needed to implement all three adaptation pathways. NNSW reference group members consistently indicated that they didn't have the farm workforce to implement the adaptation pathways or took a neutral position on assessing this capital. NNSW reference group members mentioned that contractors and staff are in short supply across the region partly due to human resources being redirected towards recovery efforts from extreme events (e.g. bushfires, floods). Human capital is a complex to manage and requires strategic planning.

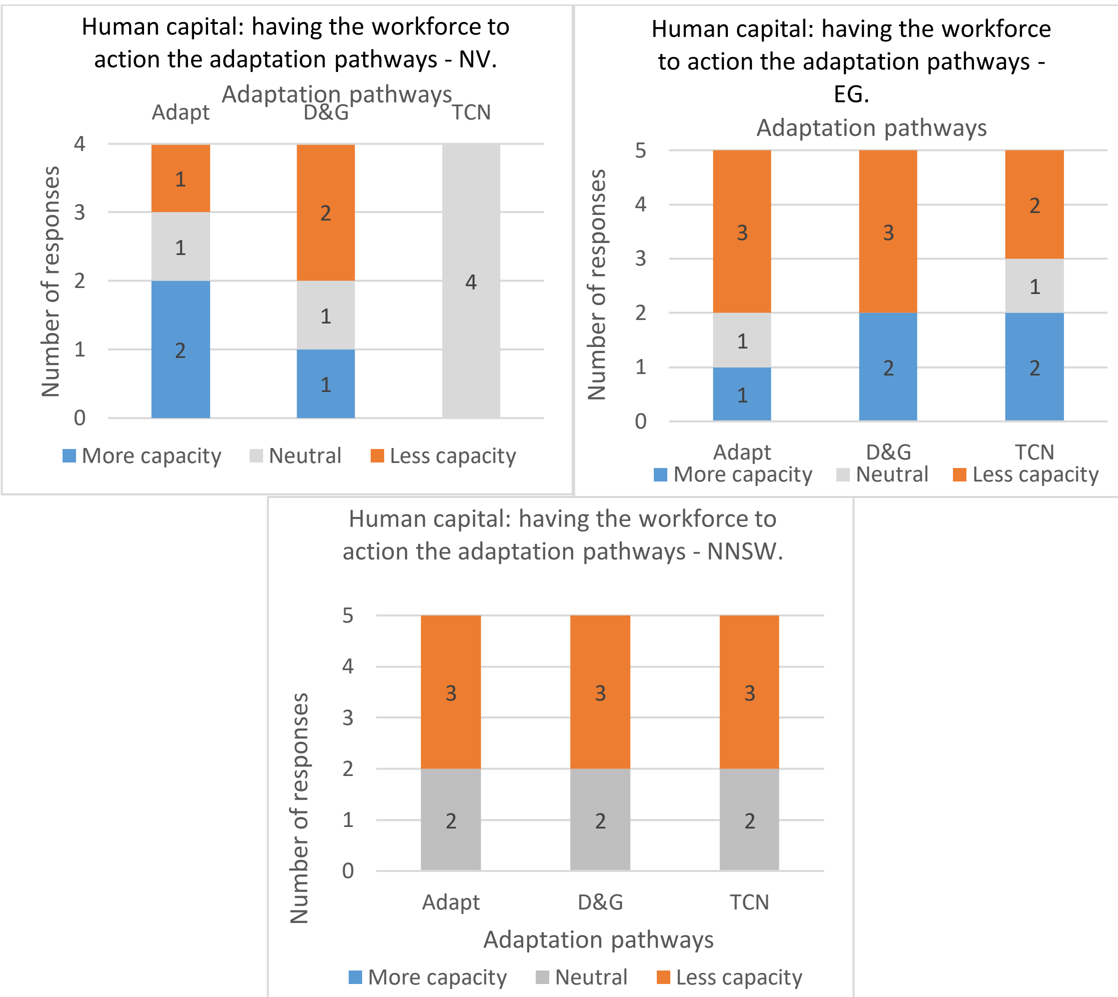

Figure 2. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to having the workforce to action the Nexus adaptation pathways.

Having choices (decision making power) about implementing the adaptation pathways– key results

All reference groups indicated that they had or their clients had the decision making power to make choices about how to implement the 'adapt' adaptation pathway (Figure 3). This may be a reflection that most producers in the Nexus reference groups are already taking actions that align with the modelled 'adapt' pathway and are therefore already demonstrating their decision making power in how they can adapt their farming systems. NV and EG reference groups indicated that they had or their clients had less capacity to make decisions about how to implement the 'towards carbon neutral' pathway i.e. they had less decision making power. Comments from EG reference group indicated that they did not perceive they had a choice about transitioning towards carbon neutral and that there wasn't many practical possibilities to implement this pathway. In contrast the NNSW reference group indicated that they had choices (decision making power) about how to implement all three adaptation pathways.

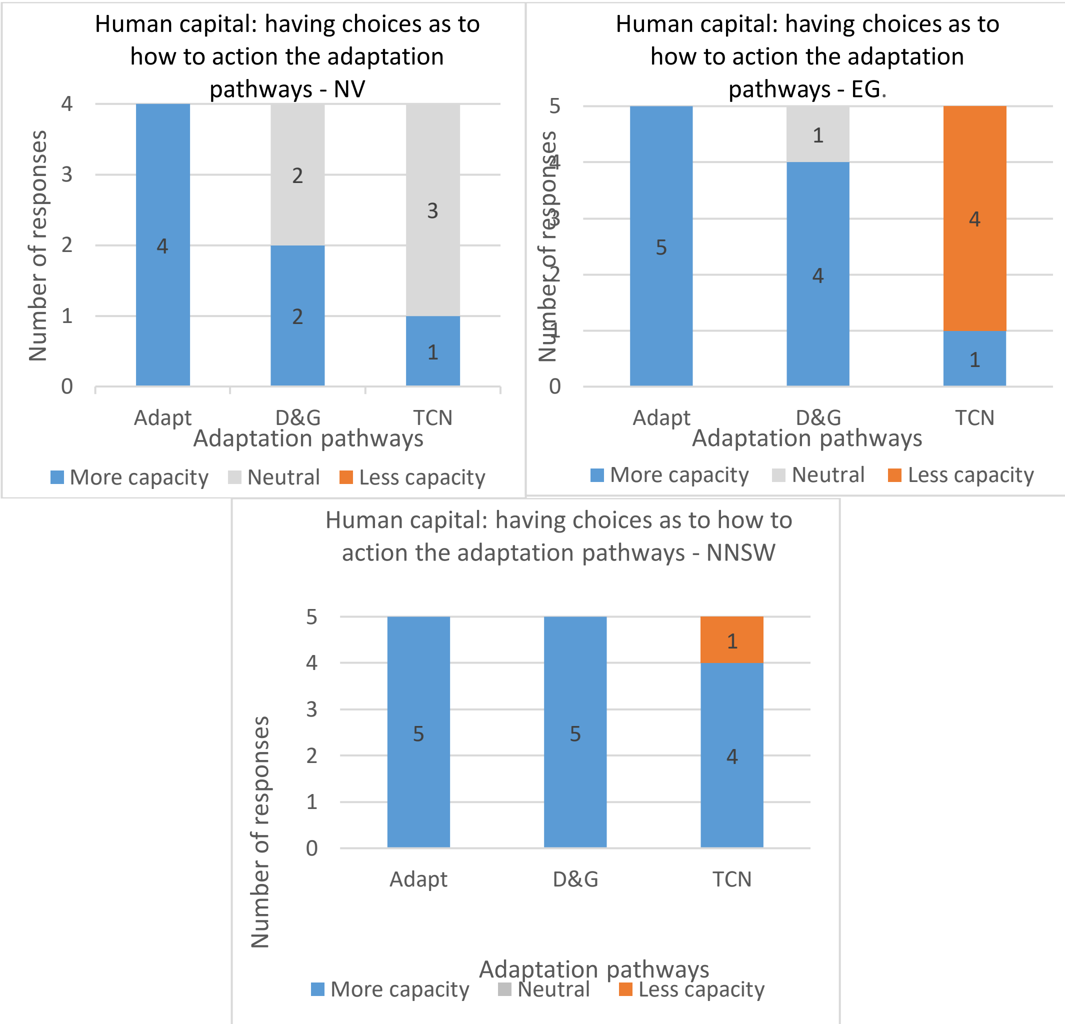

Figure 3. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to having choices as to how to action the Nexus adaptation pathways.

Self-responsibility for developing options for pathway implementation– key results

EG and NNSW reference groups generally indicated that they had more capacity in terms of considering themselves responsible for developing options for adapting, diversifying and growing and transitioning towards carbon neutral production (Figure 4). In comparison, the NV reference group indicated they had less capacity in terms of considering themselves responsible for developing options for adapting, diversifying and growing and transitioning towards carbon neutral production. However the general trend across the reference groups, is that there was less capacity for being self-responsible for developing implementation options for the 'towards carbon neutral pathway' compared to the 'adapt' and 'diversify and grow' adaptation pathways.

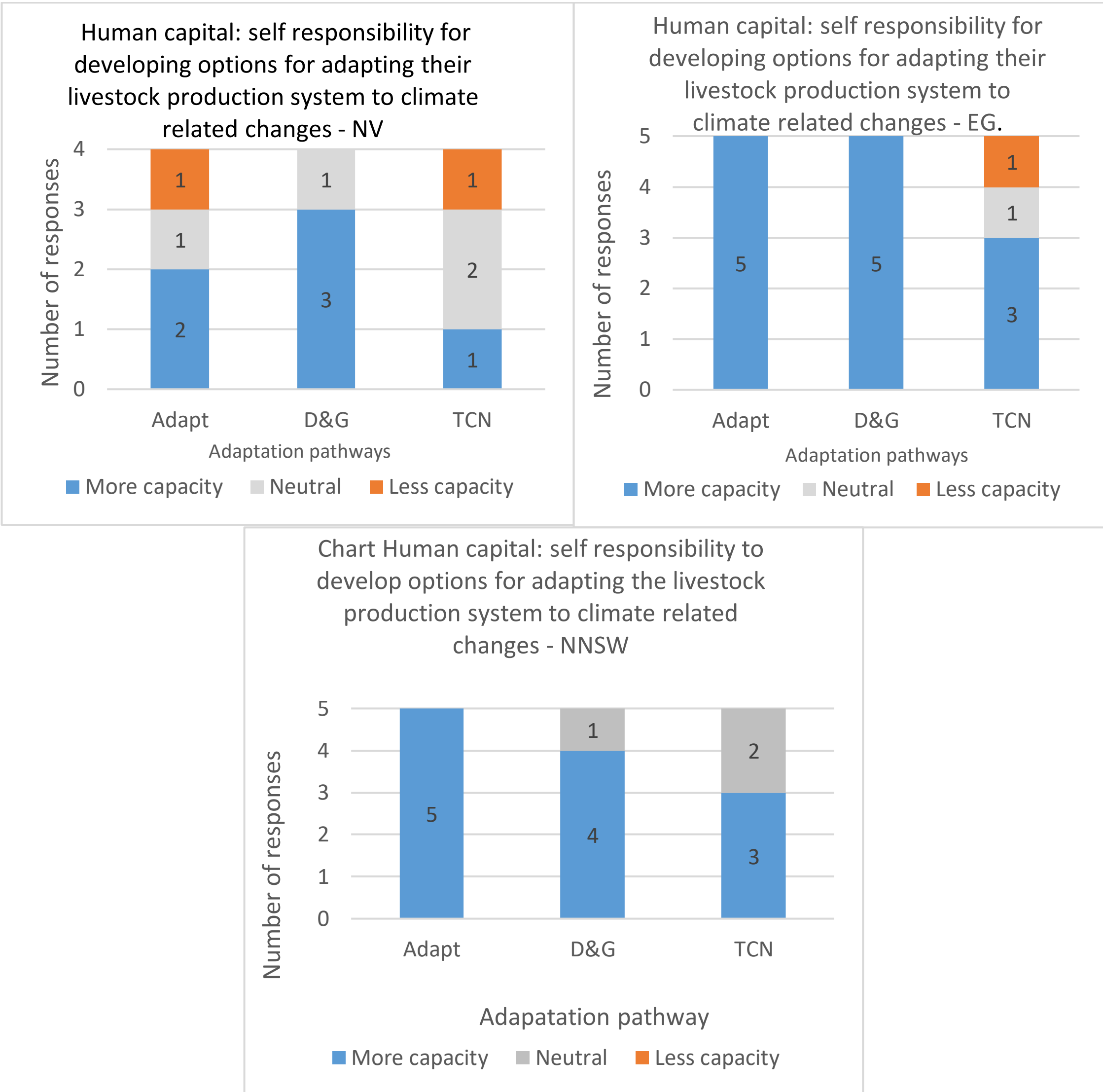

Figure 4. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to taking personal responsibility to develop options for adapting livestock production systems to climate related changes.

Knowing what steps to take for pathway implementation– key results

Overall at least half of the NV, EG and NNSW reference group members indicated that they had capacity (self-efficacy or confidence) to implement the 'adapt' and 'diversify and grow' adaptation pathways in terms of knowing what steps they need to take (Figure 5). Across all three reference groups, there was less capacity in terms of self-efficacy or confidence to implement the 'towards carbon neutral' pathway. EG reference group members indicated less capacity to 'diversify and grow' their livestock businesses compared to NV and NNSW.

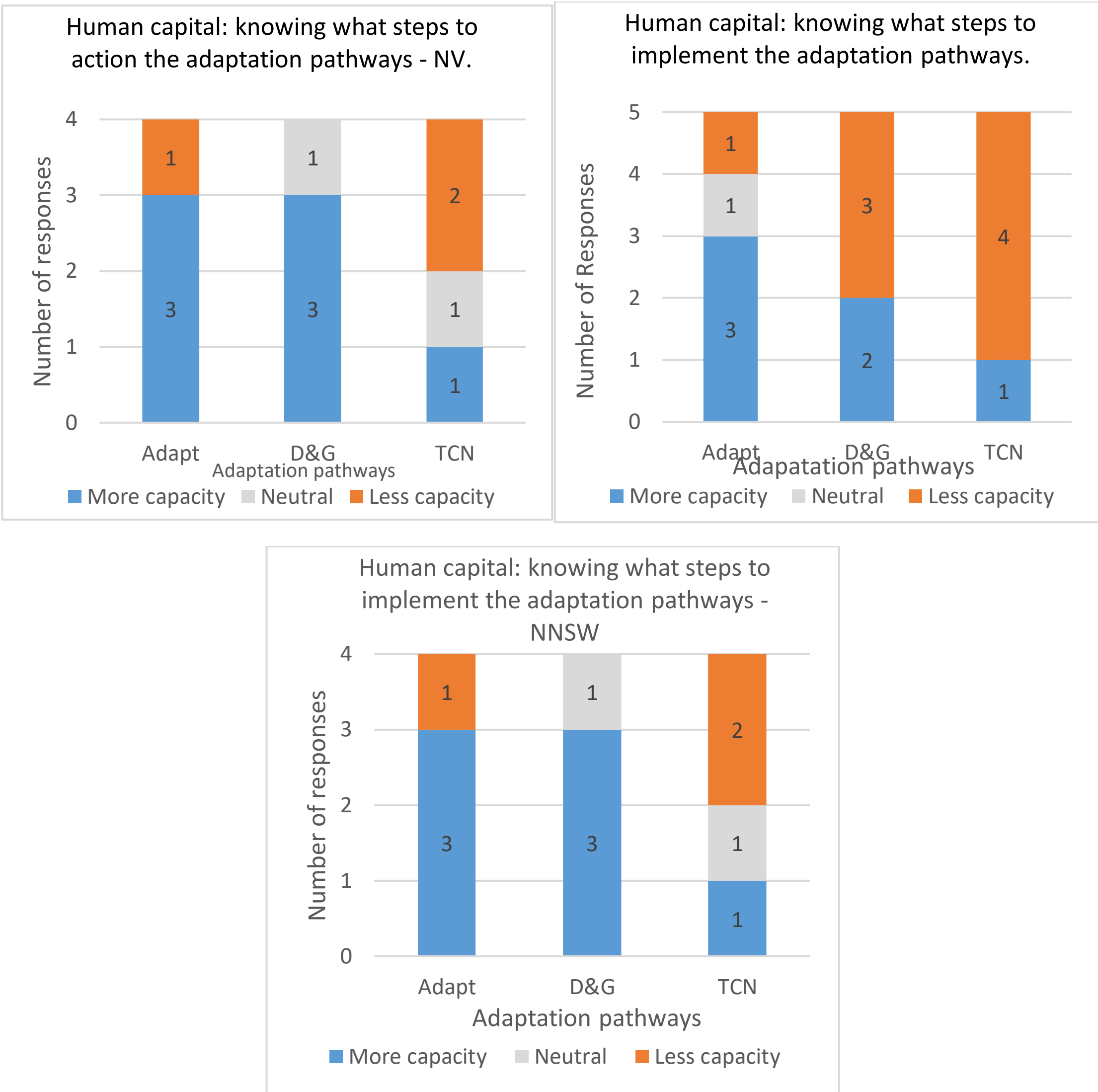

Figure 5. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to knowing what next steps are needed to action the Nexus adaptation pathways.

SOCIAL CAPITAL

Suitable government/industry policy support– key results

A general trend across the three reference groups is that there is less capacity to implement the Nexus adaptation pathways in terms of taking action within a supportive policy environment (government and industry policy) (Figure 6). Key message from the NNSW reference group that policy needs to be clearer about the GHG measuring the impacts of each GHG and accounting for GHG emissions in livestock systems. At the moment, the targets for mitigating GHG are not consistent or stable.

There was some capacity for adaptation based on having suitable government and industry support within the EG reference group. A group discussion with the EG reference group indicated that there was some acknowledgement of government endorsement for the 'towards carbon neutral' pathway however, there are limited practical policy recommendations about how to successfully implement this pathway. There was acknowledgement of industry support through R&D policy and programs, but this was constrained by project budgets, short timelines and limited human resources.

Each reference group had members who had a neutral position for this social capital. It may have been difficult to rate this social capital without referring to specific policies. Alternatively, it may have been unclear what policies were relevant to support the 'diversify and grow' adaptation pathway.

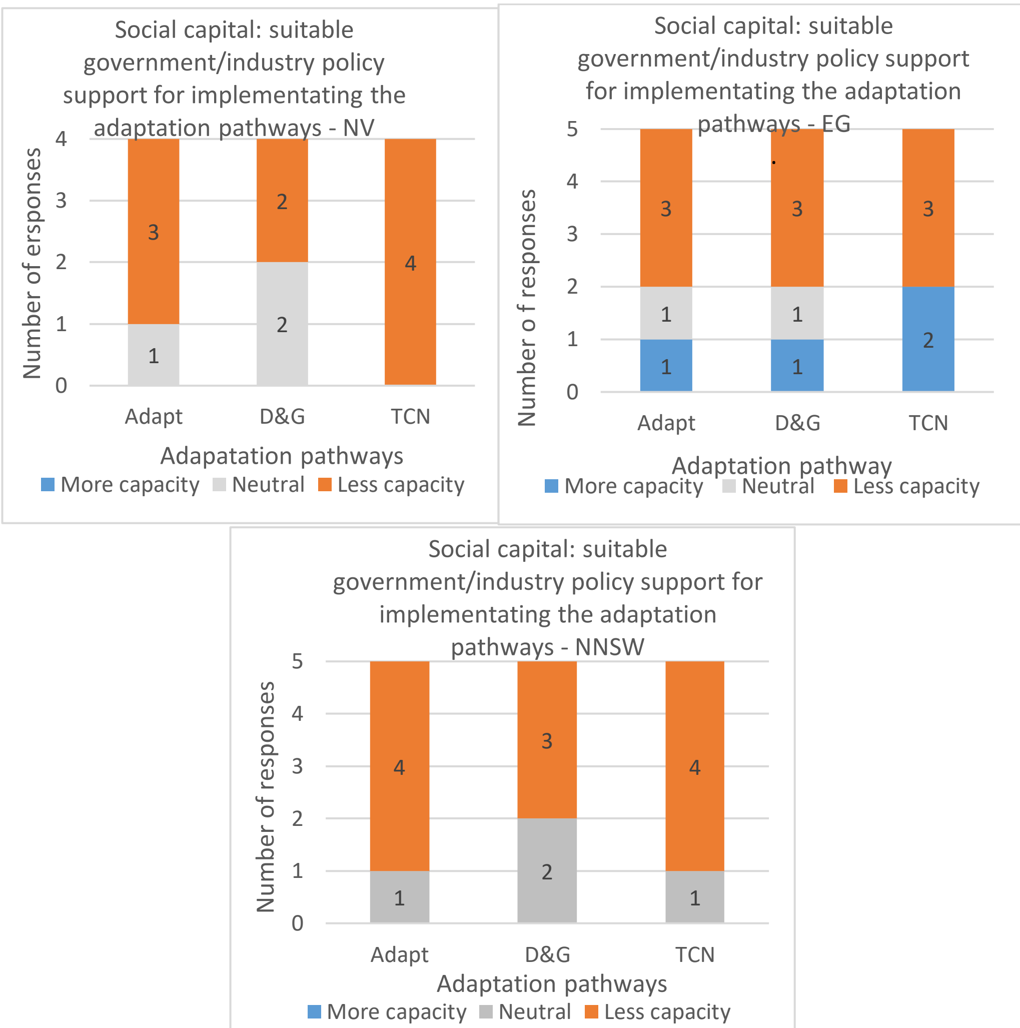

Figure 6. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to having suitable government/industry policy to support the implementation of the Nexus adaptation pathways.

Adequate regionals services and programs – key results

Unsurprisingly across all three reference groups, there was less capacity to implement the Nexus adaptation pathways in relation to having adequate regional services and programs to support climate change adaptation (Figure 7). As a general pattern, there was less capacity to implement the 'towards carbon neutral' pathway in terms of adequate regionals services and programs compared to the other adaptation pathways. The NNSW reference group consistently assessed their adaptation capacity to be constrained by the lack of available adequate regional services and programs. For EG reference group, there responses to this social capital were explained by not having their sheer numbers of personnel available to service their production area as well as the lack of training and experience of current advisers to offer trusted (paid) advice, particularly for the 'towards carbon neutral' pathway.

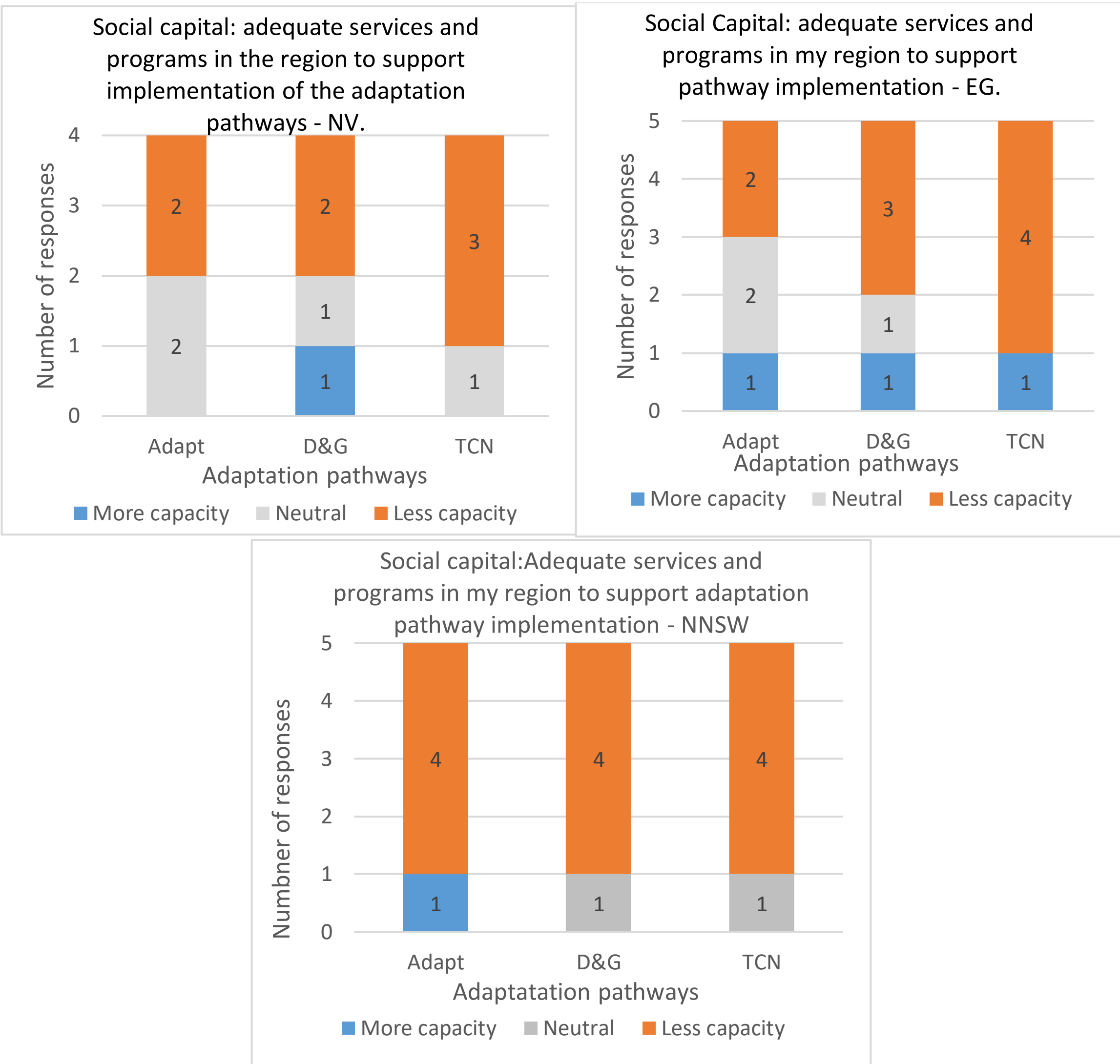

Figure 7. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to having adequate services and programs in the region to support implementation of the Nexus adaptation pathways.

Regional service providers have the capacity to develop options for pathway implementation– key results

Self-assessing adaptive capacity in terms of rating the capacity of regional service providers to develop options for implementing the Nexus adaptation pathways may be have been problematic because reference group members were unsure how to assess this type of social capital, this statement was too ambiguous or it was challenging to rate across the diversity of regional service providers operating in the region (Figure 8). The NNSW reference group consistently indicated that there was low capacity for implementing the Nexus adaptation pathways when drawing on the ability of regional service providers to develop options for 'adapting', 'diversifying and growing' and transitioning 'towards carbon neutral'. NV and EG reference groups indicated their adaptive capacity was constrained by their regional service providers to develop practical options for transitioning 'towards carbon neutral' production.

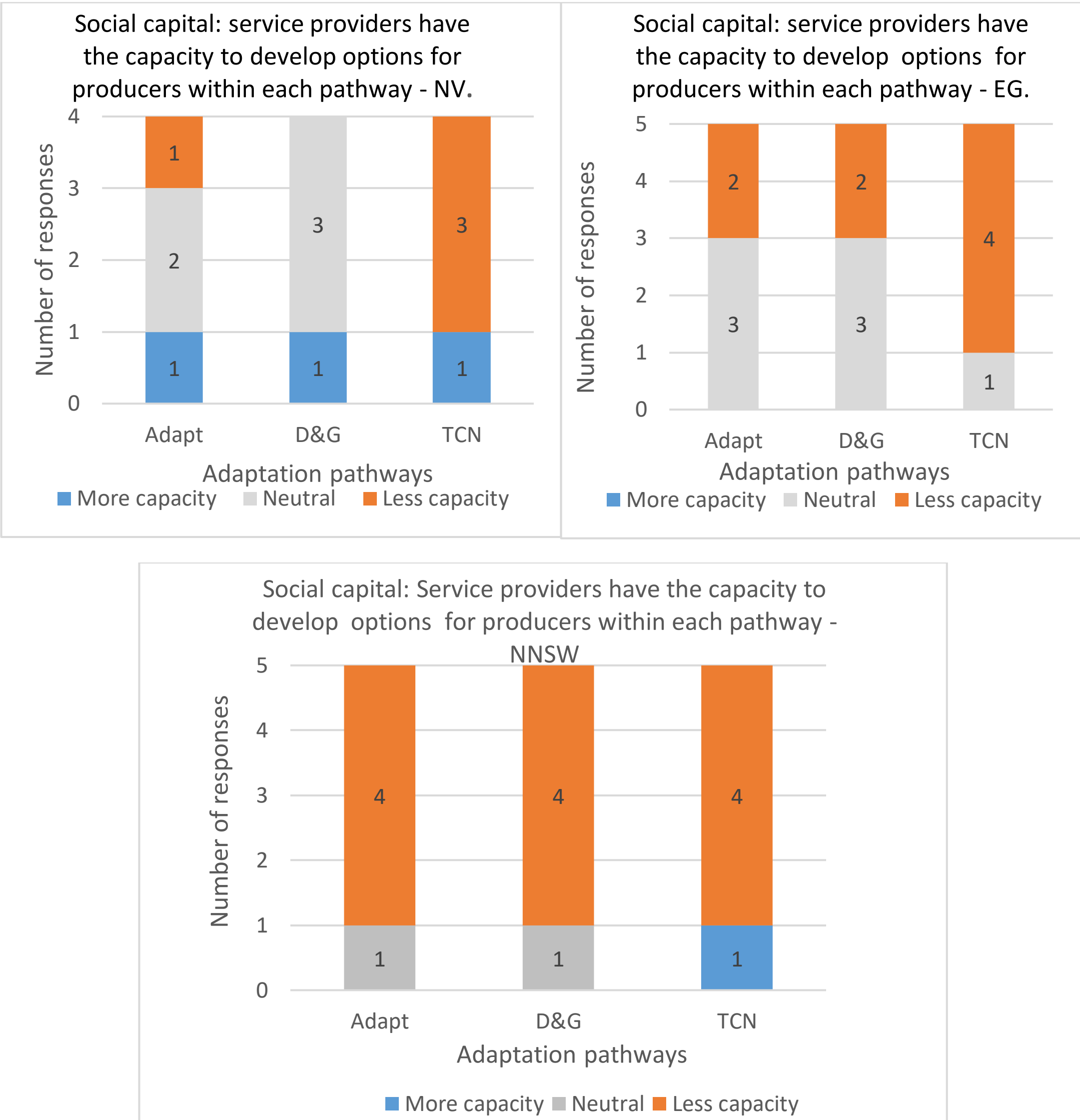

Figure 8. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to the capacity of service providers having the capacity to develop options for producers within each Nexus adaptation pathway.

Mentoring peers regarding the adaptation pathways– key results

In terms of reference group members being actively involved in building social capital through mentoring their peers on climate change adaptation, a majority of Nexus reference group members were involved in mentoring their peers along an 'adapt' pathway (Figure 9). There were some Nexus reference group members mentoring their peers along a 'diversify and grow' pathway and 'towards carbon neutral pathway'. The EG reference group indicated the most capacity for mentoring peers regarding the 'towards carbon neutral' pathway, while the NV reference group indicated the least capacity to mentor peers regarding the 'diversify and grow' pathway. It is important to acknowledge that adaptive capacity is about building capacity within the industry through producer to producer networks, and adviser to adviser networks (or Communities of Practice).

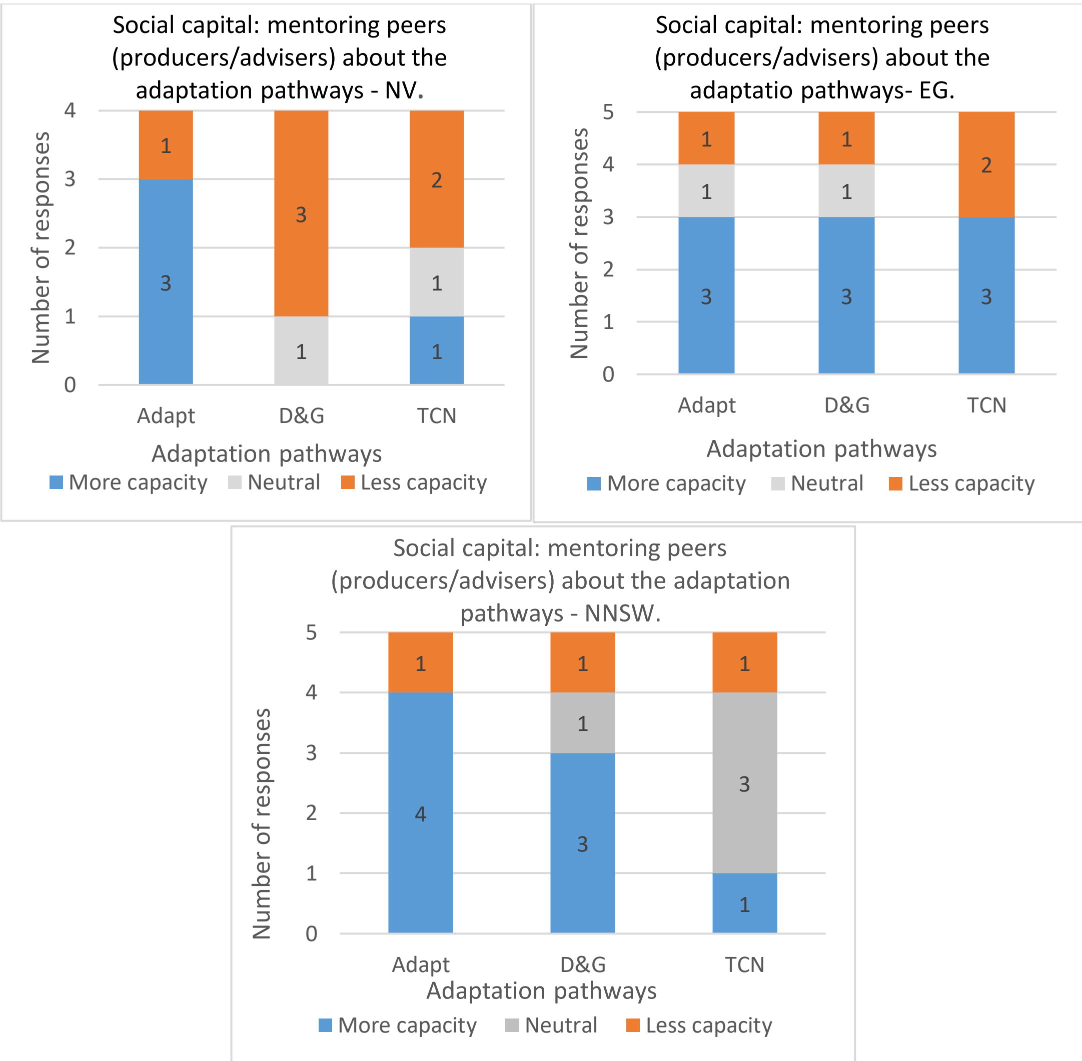

Figure 9. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to currently mentoring peers (producers/advisers) about the Nexus adaptation pathways.

Participating in social networks for learning about the adaptation pathways– key results

Overall the EG and NNSW reference groups indicated more adaptive capacity in terms of current participation in social learning networks to learn more about the Nexus adaptation pathways compared to the NV reference group (Figure 10). There EG and NNSW reference groups may have involved particularly socially active producers and advisers and/or these regions may have developed strong industry/peer networks to exchange new information, knowledge and practices as a social norm.

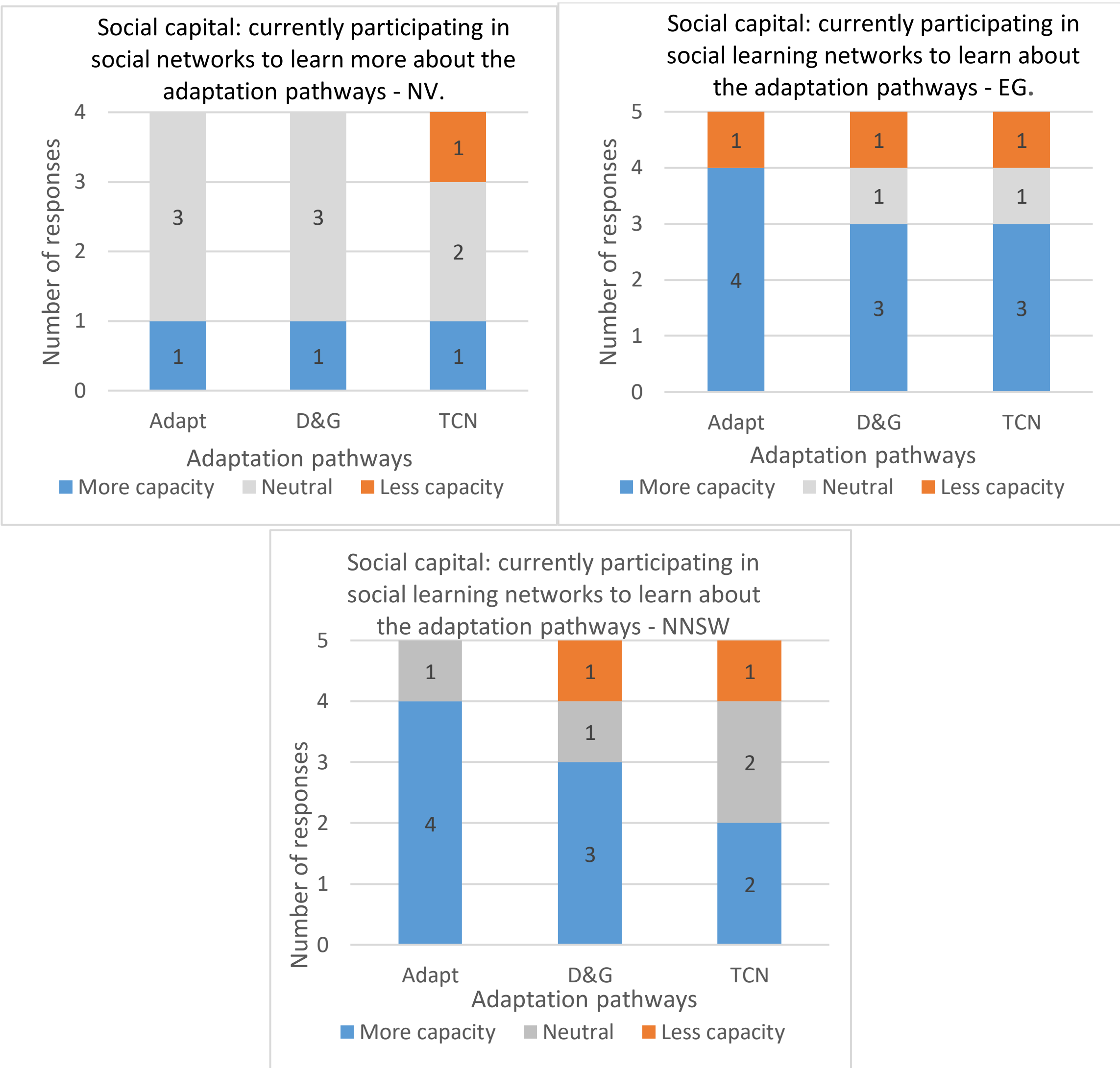

Figure 13. Stacked bar charts showing the frequency and split of responses per reference group across the categories of 'more capacity', 'neutral' or 'less capacity' with regards to currently participating in social (learning) networks to learn more about the Nexus adaptation pathways (general features).

Characteristics of reference group members

PRODUCERS			
	Northern Victorian RG	**East Gippsland RG**	**Northern NSW RG**
Age Range	1 - 55-64 1 – 65-74	2 -35-44 1- 45-54 1 - 55-64	2 -35-44 1 - 55-64 1 – 65-74
Property size (ha)	1850 2600	600 1320 1400 120	1350 4169 607 2743
Main livestock business	breeding cattle. prime lamb beef breeding and finishing, merino wool and mutton production	breeder cattle, lambs cattle breeder beef, sheep Trading cattle and breeder cattle	Merino stud Wool Breeder cattle; producing vealers, yearlings, and restocker weaners. wool sheep, first cross lamb and beef cattle breeder
Other enterprises		Bobby calf buyer	Cattle trading, self replacing merinos, dual purpose winter cropping Wheat We are an equal third split for our business across the three enterprises mentioned above
Years involved in livestock production	1 - 31-40 1 – more than 40	2 – less than 10 1-11-20 1- 21-30	2- 21-30 1 - 31-40 1 – more than 40
Business stage	1 – process of family succession 1 – half between establishment and family succession	1 – Established 3 – expanding/growing	1 – Established 1 – expanding/growing 1 - process of family succession 1 – expanding/growing business as part of family succession planning
Workforce FTE	1 – 2 employees 1 – 0.5 family, 3 employees, many contractors	1 – 1 employee 1 – 0.4 family, 0.7 employee 1 – 2 family, 1 employee 1 – self	1 – 1 family, 1 employee, 4 contractors 1 – 2 family 1 – 1 family, 1.5 employees, 2.5 contractors 1 –3 family, 2 employees

ADVISERS			
	Northern Victorian RG	**East Gippsland RG**	**Northern NSW RG**
Age Range	1 - 55-64 1 – 65-74	1 – 55-64	1 – 75 or older
Clients serviced	200 20	100	Do lots of field days, meetings, media and farm visits.
Main services provided	Pasture agronomy, grazing management , sheep & beef cattle management (management calendars, genetics, nutrition), farm business analysis & benchmarking. Pasture agronomy and sheep and cattle management	Animal health, grazing management, reproductive management, nutrition, stocking rate	pastures, fodder crops, soil management
Years involved as an advisor	1 - 31-40 1 – more than 40	11-20	More than 40 years

Copy of the self-assessment of adaptive capacity questionnaire for the Nexus Project: adviser version for the NNSW Reference Group

Thank you for filling out our survey. They survey will ask you to respond to a series of statements about how you view your ability to adapt and mitigate GHG emissions based on the availability, access and use of different types of resources.

Types of resources	Examples
Human	capacity to learn, human resource management, decision-making and prioritizing, skills and knowledge, motivation, attitudes towards risk and uncertainty
Social	family unit, formal and informal social networks, access and contributions to information/services, engagement with policy and governance system
Financial	cost of production, access to income/credit, land price, freight costs, financial policy
Physical	general infrastructure (e.g. machinery, irrigation, fencing) and specific farm infrastructure for responding to climate change (e.g. feed pads, water monitoring technologies), road and rail networks, regional water infrastructure
Natural	pests/weeds/diseases, pasture/crop species and genetics, water resources, soil health, biodiversity, land capability, animal health and genetics
Cultural	Influence of family norms, community values, food production ethics

Your adaptive capacity will be mainly explored using the Nexus project's three adaptive pathways that have been modelled: adapt, diversify and towards carbon neutral. A quick reminder of what each pathway is about:

Adapt – better livestock production through farm system improvements. These include increase arable area of farm from 320 to 500 ha, and sowing arable area to tropical grass/subclover mix and increasing lamb survival rate of multiples (twins, triplets) from 80 to 90% (achieved through use of smaller mob sizes, with additional fencing, water points and labour to be factored in).

Diversify and Grow – this includes all the changes in the 'Adapt' pathway, plus buy 1000 ha of fairly undeveloped, light county at Binnaway to be used for livestock production, trees and biodiversity to diversify income streams.

Towards Carbon Neutral - this includes all the changes in the 'Adapt' pathway, plus use of trees (managed regrowth and plantings) on up to 20% of non-arable area in the steep gullies and riparian areas, possible soil carbon accumulation on sown tropical grass pastures (to be determined), and opportunities to include feed additives in supplementary feed to reduce methane (fed in paddock).

Transformative Research & Development - adapting to a changing climate by taking advantage of the latest technologies, products and services that may be developed through industry R&D and related innovation activities.

Projected regional climate out to 2050 – while a broad range of climate scenarios have been used for the modelling, broadly speaking the most notable features are a continuation of the warmer trend, with increasing rainfall in autumn and declining rainfall in winter and spring for the Northern NSW region.

The survey is expected to take approximately 30 minutes and is completely voluntary - you may withdraw at any stage.

ADAPT PATHWAY – adapting to a changing climate through making tactical improvements to the current farm system.					
Capital	**Rating scale – Please circle a number for your answer 1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree**				
1. HUMAN	a) I have the knowledge and skills or can access the knowledge and skills needed for the adapt pathway.	b) It is primarily my responsibility to develop options for adapting my livestock production system to climate related changes.	c) I have the workforce I need to support the implementation of the adapt pathway.	d) I know what steps I need to take to achieve a more adapted livestock production system.	e) I think that I have choices as to how I adapt my livestock production system.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2. SOCIAL	a) Currently we have suitable government/industry policy to support the adaptation of livestock businesses.	b) I have mentored other producers about adapting their livestock production system in response to climate related changes.	c) There are adequate services and programs in my region to support producers to adapt our livestock production systems in response to climate related changes.	d) Service providers have the capacity to develop adaptation options for producers in response to climate related changes.	e) As a result of building connections with local networks and international contacts I am learning about how to adapt my livestock production system.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
3. FINANCIAL	a) Adapting my livestock production system will be an affordable cost to my business.	b) There is likely to be a good return on investment from adapting my livestock production system.	c) The current terms of trade are favourable for investing in adapting my livestock production system.	d) Currently the financial sector provides a range of financial products to support producers in adapting to climate related changes.	e) I have a high capacity to invest in new ways to adapt my livestock production system based on my current financial situation.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
4. PHYSICAL	a) I currently have the farm infrastructure and equipment (including technologies) needed to adapt to climate related changes on my property.	b) Producers in my region currently have the farm infrastructure and equipment (including technologies) needed to adapt their livestock production systems for responding to climate related changes on their properties.	c) My region has extensive and functional transport infrastructure that supports me to adapt my livestock production system in response to climate related changes.	d) My region has extensive and functional digital communications networks that supports me to adapt my livestock production system in response to climate related changes.	e) My region has extensive and functional water infrastructure that supports me to adapt my livestock production system in response to climate related changes.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
5. NATURAL	a) My property is in a climate zone that will enable me to adapt my livestock production system out to 2050.	b) I already have the biodiversity on my property, which will assist me in adapting to climate related changes on my property.	c) Adapting my livestock production system is not currently constrained by the water resources I can access/ store on my property.	d) The soil types on my property provide the opportunity to experiment with different pasture species for adapting.	e) The breed(s) of livestock that I currently have assist me with adapting to climate related changes.

<table>
<tr><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td colspan="26">DIVERSIFY AND GROW PATHWAY – adapting to a changing climate through developing a larger system whereby fixed costs can be spread over greater output.</td></tr>
<tr><td>Capital</td><td colspan="25">Rating scale – Please circle a number for your answer
1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree</td></tr>
<tr><td rowspan="2">6.
HUMAN</td><td colspan="5">a) I have the knowledge and skills or can access the knowledge and skills needed for the diversify and grow pathway.</td><td colspan="5">b) It is primarily my responsibility to develop options for diversifying and growing my livestock production system.</td><td colspan="5">c) I have the workforce I need to support the implementation of the diversify and grow pathway.</td><td colspan="5">d) I know what steps I need to take to achieve a more diversified and expanded livestock production system.</td><td colspan="5">e) I think that I have choices as to how I diversify and grow my livestock production system.</td></tr>
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<tr><td rowspan="2">7.
SOCIAL</td><td colspan="5">a) Currently we have suitable government/industry policy to support the diversification and growth of livestock businesses.</td><td colspan="5">b) I have mentored other producers about diversifying and growing their livestock production system.</td><td colspan="5">c) There are adequate services and programs in my region to support producers to diversify our livestock production systems in response to climate related changes.</td><td colspan="5">d) Service providers have the capacity to develop options for producers to diversify and grow their livestock businesses to adapt to climate related changes.</td><td colspan="5">e) As a result of building connections with local networks and international contacts I am learning about how to diversify and grow my livestock production system.</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="2">8.
FINANCIAL</td><td colspan="5">a) Diversifying and growing my livestock production system will be an affordable cost to my business.</td><td colspan="5">b) There is likely to be a good return on investment from diversifying and growing our livestock production system in response to climate related changes.</td><td colspan="5">c) The current terms of trade are favourable for investing in diversification and growing my livestock production system.</td><td colspan="5">d) Currently the financial sector provides a range of financial products to support producers in diversifying and growing their livestock production system in response to climate change.</td><td colspan="5">e) I have a high capacity to invest in new ways to diversify and grow my livestock production system based on my current financial situation.</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="2">9.
PHYSICAL</td><td colspan="5">a) I currently have the farm infrastructure and equipment (including technologies) needed to diversify and grow my livestock production system for responding to climate related changes on my property.</td><td colspan="5">b) Producers in my region currently have the farm infrastructure and equipment (including technologies) needed to diversify and grow their livestock production systems for responding to climate related changes on their properties.</td><td colspan="5">c) My region has extensive and functional transport infrastructure that supports me to diversify and grow my livestock production system in response to climate related changes.</td><td colspan="5">d) My region has extensive and functional digital communications networks that supports me to diversify and grow my livestock production system in response to climate related changes.</td><td colspan="5">e) My region has extensive and functional water infrastructure that supports me to diversify and grow my livestock production system in response to climate related changes.</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>10.
NATURAL</td><td colspan="5">a) My property is in a climate zone that will enable me to diversify and grow my livestock business out to 2050.</td><td colspan="5">b) I already have the biodiversity on my property that will assist me in diversifying and growing my income streams as a response to climate related changes.</td><td colspan="5">c) Diversifying and growing my livestock production system is not currently constrained by the water resources I can access/store on my property.</td><td colspan="5">d) The soil types on my property provide the opportunity to experiment with different pasture species for diversifying and growing.</td><td colspan="5">e) The breed(s) of livestock that I currently have assist me with diversifying and growing my production system in response to climate related changes.</td></tr>
</table>

	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
TOWARDS CARBON NEUTRAL PATHWAY – adapting to a changing climate by reducing greenhouse gas emissions, turning of livestock earlier and practising agroforestry.																									
Capital	**Rating scale – Please circle a number for your answer 1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree**																								
11. HUMAN	a) I have the knowledge and skills or can access the knowledge and skills needed for transitioning towards a carbon neutral livestock production system.					b) It is primarily my responsibility to develop options for transitioning towards a carbon neutral livestock production system.					c) I have the workforce I need to support the implementation of the Towards Carbon Neutral pathway.					d) I know what steps I need to take to achieve a carbon neutral livestock production system.					e) I think that I have choices as to how I transition my livestock production system towards carbon neutral.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
12. SOCIAL	a) Currently we have suitable government/industry policy to support the transition of livestock production systems towards carbon neutral.					b) I have mentored other producers about transitioning towards a carbon neutral livestock production system.					c) There are adequate services and programs in my region to support producers to transition our livestock production systems toward carbon neutral.					d) Service providers have the capacity to develop options for producers to transition their livestock production systems towards carbon neutral.					e) As a result of building connections with local networks and international contacts I am learning about how to transition my livestock production system towards carbon neutral.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
13. FINANCIAL	a) Transitioning my livestock production system towards carbon neutral will be an affordable cost to my business.					b) There is likely to be a good return on investment from transitioning my livestock production system towards carbon neutral.					c) The current terms of trade are favourable for investing in transitioning towards a carbon neutral livestock production system.					d) Currently the financial sector provides a range of financial products to support producers in transitioning towards carbon neutral livestock production.					e) I have a high capacity to invest in ways for my livestock business to transition towards carbon neutral based on my current financial situation.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
14. PHYSICAL	a) I currently have the farm infrastructure and equipment (including technologies) needed to transition my livestock production system towards carbon neutral on my property.					b) Producers in my region currently have the farm infrastructure and equipment (including technologies) needed to transition their livestock production systems towards carbon neutral on their property.					c) My region has extensive and functional transport infrastructure that supports a transition towards a carbon neutral livestock production system.					d) My region has extensive and functional digital communications networks that supports a transition towards a carbon neutral livestock production system.					e) My region has extensive and functional water infrastructure that supports a transition towards a carbon neutral livestock production system.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
15. NATURAL	a) My property is in a climate zone that enables me to sequester carbon in the soils and vegetation out to 2050.					b) I already have the biodiversity on my property to enable a transition towards a carbon neutral livestock production system.					c) Transitioning my livestock production system towards carbon neutral is not currently constrained by the water resources I can access/store on my property.					d) The soil types on my property provide the opportunity to experiment with different flora for carbon sequestration.					e) The breed(s) of livestock that I currently have assist me with transitioning my livestock production system towards carbon neutral.				

	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

SUPPLEMENTARY QUESTIONS

Cultural capital

Capital	**Rating scale – Please circle a number for your answer** **1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree**				
16. CULTURAL	a) My family is often involved in decision making and is interested in how to adapt our livestock production system.				
	1	2	3	4	5
	b) It is important to engage with Aboriginal and Torres Strait peoples to learn new knowledge and practices and exchange knowledge and practices in land management and responsibilities in caring for Country.				
	1	2	3	4	5
	c) Community issues and values on food production are important and influence the choices I make on my property.				
	1	2	3	4	5
	d) Our local community readily shares knowledge, ideas, and experiences for the good of everyone.				
	1	2	3	4	5
	e) Producers are supportive of each other, and the way livestock production is done in this area.				
	1	2	3	4	5

Transformative Research & Development pathway

The transformative pathway that is to be modelled aims to adapt to a changed climate by adopting and implementing innovations that have been developed through R&D, innovations that are not technically feasible at present. For example, it is assumed that over time it will be possible to use a vaccination delivery for a methane reducing supplement to livestock. We are interested in capturing what else you might consider as transformational change for adapting to a changing climate.

17. What does transformational change look like to you for your production system? Give examples of change you have seen or implemented yourself that you think represents transformational change.

18. What might be the implications from livestock producers transforming their livestock production system in the way that you have described it above ? (e.g. for your business, local community, agricultural sector in your region, livestock industry?)

General

19. How likely are you to consider the “adapt” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already on this pathway
1	2	3	4	5	6

20. How likely are you to consider the “diversify and grow” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already on this pathway
1	2	3	4	5	6

21. How likely are you to consider the “toward carbon neutral” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already on this pathway
1	2	3	4	5	6

22. How likely are you to consider the “transformational” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already on this pathway
1	2	3	4	5	6

23. Describe one or more changes you have already made to manage your livestock production system in response to climate related changes.

24. Describe any future changes you are planning for improving the management of your livestock production system in response to climate related changes.

25. What are your key sources of information and advisory services that you use to consider for making decisions or keeping yourself informed about climate-related changes? (e.g. internet, social media, printed media, specific consultants, other producers, industry organisations)

26. What farming knowledge is specific to your region that is not relevant to other places?

27. What do you see as the gaps in current extension and advisory services to support producers in adapting and mitigating climate-related change?

28. Please describe any new extension and advisory services that you think are needed for adapting and mitigating climate-related change? (i.e. currently unavailable)

29. List what you think should be the top 3 priorities for research and development project funding over the next five years that will enable adaptation to climate related changes in the livestock industries.

30. Do you have any other comments you would like to make about adapting livestock businesses to climate-related change?

Demographic and production system information

31. Age range (place an X in appropriate box)	18-24 years old	
	25-34 years old	
	35-44 years old	
	45-54 years old	
	55-64 years old	
	65-74 years old	
	75 years or older	

32. Property size: ha	

33. Main livestock business:	

34. Other agricultural enterprises:	

35. How many years have you been involved in livestock production?	10 years or less	
	11-20 years	

(place an X in appropriate box)	21-30 years	
	31-40 years	
	More than 40 years	

36. Which of the following best describes the stage you are at in farming? **(place an X in appropriate box)**	Established	
	Expanding/growth	
	In the process of planned succession to next generation	
	Winding down operations (no succession)	
	Other (please specify)	

	Workforce	**How many**	**FTE**
37. Please indicate your current workforce besides yourself	Family members		
	Employees (casual, part-time or full-time)		
	Contractors		
	Other (please specify)		

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Cultural	Influence of family norms, community values, food production ethics

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Projected regional climate out to 2050 – while a broad range of climate scenarios have been used for the modelling, broadly speaking the most notable features are a continuation of the warmer trend, with increasing rainfall in autumn and declining rainfall in winter and spring for the Northern NSW region.

The survey is expected to take approximately 30 minutes and is completely voluntary - you may withdraw at any stage.

ADAPT PATHWAY – adapting to a changing climate through making tactical improvements to the current farm system.

Capital					
	Rating scale – Please circle a number for your answer **1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree**				
1. HUMAN	a) I am confident my clients have the knowledge and skills or can access the knowledge and skills needed for the adapt pathway.	b) It is primarily my clients' responsibility to develop options for adapting to climate change.	c) My clients have the workforce they need to support the implementation of the adapt pathway.	d) My clients know what steps they need to take to achieve a more adapted livestock production system.	e) My clients have choices as to how they adapt their livestock production systems.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2. SOCIAL	a) Currently we have suitable government/industry policy to support the adaptation of livestock businesses.	b) I have mentored other advisers about adapting their clients' livestock production systems in response to climate related changes.	c) There are adequate services and programs in my region to support producers to adapt their livestock production systems in response to climate related changes.	d) Service providers have the capacity to develop adaptation options for producers in response to climate related changes.	e) As a result of building connections with local networks and international contacts I am learning about how to advise my clients to adapt their livestock production systems.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
3. FINANCIAL	a) Adapting livestock businesses will be an affordable added cost for my clients.	b) There is likely to be a good return on investment from my clients adapting their livestock production system.	c) The current terms of trade are favourable for my clients to be investing in adapting their livestock production systems.	d) Currently the financial sector provides a range of financial products to support producers in adapting to climate related changes.	e) My clients generally have a high capacity to invest in new ways to adapt their livestock business based on their current financial situation.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
4. PHYSICAL	a) Currently I have the infrastructure and equipment (including technologies) I need to advise my clients on adapting to climate related changes.	b) Currently my clients have the infrastructure and equipment (including technologies) needed to adapt to future climate-related changes on their property.	c) The region I work in has extensive and functional transport infrastructure that supports my clients in adapting their livestock production systems to climate related changes.	d) The region I work in has extensive and functional digital communications networks that supports my clients in adapting their livestock production systems to climate related changes.	e) The region I work in has extensive and functional water infrastructure that supports my clients in adapting their livestock production systems to climate related changes.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
5. NATURAL	a) My clients are in a climate zone that will enable them to adapt their livestock production system out to 2050.	b) My clients already have the biodiversity on their properties, which will assist them in adapting to climate related changes on their properties.	c) My clients' capacities to adapt to climate related changes are not currently constrained by their access/storage of water resources on their property.	e) The soil types on my clients' properties provide them with the opportunity to experiment with different pasture species for adapting.	f) The breed(s) of livestock that my clients currently have assists them with adapting to climate related changes.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

DIVERSIFY AND GROW PATHWAY – adapting to a changing climate through developing a larger system whereby fixed costs can be spread over greater output.				
Capital	**Rating scale – Please circle a number for your answer 1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree**				
6. HUMAN	a) I am confident my clients have the knowledge and skills or can access the knowledge and skills needed for the diversify and grow pathway.	b) It is primarily my clients' responsibility to develop options for diversifying and growing their livestock production systems.	c) My clients have the workforce they need to support the implementation of the diversify and grow pathway.	d) My clients know what steps they need to take to achieve a more diversified and expansive livestock production system.	e) My clients have choices as to how they will diversify and grow their livestock production systems.
	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5
7. SOCIAL	a) Currently we have suitable government/industry policy to support the diversification and growth of livestock businesses.	b) I have mentored other advisers about diversifying and growing their clients' livestock production systems in response to climate related changes.	c) There are adequate services and programs in my region to support producers to diversify and grow their livestock production systems in response to climate related changes.	d) Service providers have the capacity to develop diversification and growth options for producers in response to climate related changes.	e) As a result of building connections with local networks and international contacts I am learning about how to advise my clients to diversify and grow their livestock production systems.
	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5
8. FINANCIAL	a) Diversifying and growing livestock businesses will be an affordable added cost for my clients.	b) There is likely to be a good return on investment from my clients diversifying and growing their livestock production system.	c) The current terms of trade are favourable for my clients to be investing in diversifying and growing their livestock production system.	d) Currently the financial sector provides a range of financial products to support producers in diversifying and growing their livestock businesses.	e) My clients generally have a high capacity to invest in new ways to diversify and grow their livestock business based on their current financial situation.
	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5
9. PHYSICAL	a) Currently I have the infrastructure and equipment (including technologies) I need to advise my clients on diversifying and growing livestock production systems in response to climate related changes.	b) Currently my clients have the farm infrastructure and equipment (including technologies) needed to diversify their income streams in response to climate related changes on their properties.	c) The region I work in has extensive and functional transport infrastructure that supports my clients to diversify and grow their production system in response to climate related changes.	d) The region I work in has extensive and functional digital communications networks that supports my clients to diversify and grow their production systems in response to climate related changes.	e) The region I work in has extensive and functional water infrastructure that supports my clients to diversify and grow their production systems in response to climate related changes.
	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5
10. NATURAL	a) My clients are in a climate zone that will enable them to diversify and grow their livestock production system out to 2050.	b) My clients already have the biodiversity on their properties, which will assist them in diversifying and growing their livestock production system.	c) My clients' capacities to diversify and grow are not currently constrained by their access/storage of water resources on their property.	e) The soil types on my clients' properties provide them with the opportunity to experiment with different pasture species for diversifying and growing their livestock businesses.	f) The breed(s) of livestock that my clients currently have assists them with diversifying and growing their livestock businesses in a changing climate.
	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5	1 | 2 | 3 | 4 | 5

TOWARDS CARBON NEUTRAL PATHWAY – adapting to a changing climate by reducing greenhouse gas emissions, turning of livestock earlier and practising agroforestry.					
Capital	**Rating scale – Please circle a number for your answer 1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree**				
11. HUMAN	a) I am confident my clients have the knowledge and skills or can access the knowledge and skills needed for the toward carbon neutral pathway.	b) It is primarily my clients' responsibility to develop options for transitioning their livestock production systems towards carbon neutral.	c) My clients have the workforce they need to support the implementation of the towards carbon neutral pathway.	d) My clients know what steps they need to take to transition their livestock production system towards carbon neutral.	e) My clients have choices as to how they transition their livestock production systems towards carbon neutral.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
12. SOCIAL	a) Currently we have suitable government/industry policy to support the transition of livestock businesses towards carbon neutral.	b) I have mentored other advisers about supporting their clients in transitioning towards a carbon neutral livestock production system.	c) There are adequate services and programs in my region to support livestock producers to transition their livestock production systems towards carbon neutral.	d) Service providers have the capacity to develop carbon neutral options for livestock producers.	e) As a result of building connections with local networks and international contacts I am learning about how to advise my clients in transitioning towards carbon neutral agriculture.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
13. FINANCIAL	a) Transitioning towards carbon neutral agriculture will not be an added cost to my clients' production systems.	b) There is likely to be a good return on investment from my clients transitioning their livestock business towards carbon neutral.	c) The current terms of trade are favourable for my clients to invest in transitioning towards a carbon neutral production system.	d) Currently the financial system provides a range of financial products to support producers in transitioning agriculture towards carbon neutral agriculture.	e) My clients generally have a high capacity to transition towards carbon neutral based on their current financial situation.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
14. PHYSICAL	a) Currently I have the infrastructure and equipment (including technologies) I need to advise my clients on transitioning their livestock production systems towards carbon neutral.	b) Currently my clients have the farm infrastructure and equipment (including technologies) needed to transition their production systems towards carbon neutral.	c) The region I work in has extensive and functional transport infrastructure that supports a transition towards carbon neutral livestock production.	d) The region I work in has extensive and functional digital communications networks that supports a transition towards carbon neutral livestock production.	e) The region I work in has extensive and functional water infrastructure that supports a transition towards carbon neutral livestock production.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
15. NATURAL	a) My clients are in a climate zone that will enable them to transition their livestock production system towards carbon neutral out to 2050.	b) My clients already have the biodiversity on their properties, which will assist them in transitioning their livestock production system towards carbon neutral.	c) My clients' capacities to transition towards carbon neutral are not currently constrained by their access/storage of water resources on their property.	e) The soil types on my clients' properties provide them with the opportunity to experiment with different flora for transitioning towards carbon neutral livestock production.	f) The breed(s) of livestock that my clients currently have assists them with transitioning their livestock businesses towards carbon neutral.
	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

SUPPLEMENTARY QUESTIONS

Cultural capital

Capital	Rating scale – Please circle a number for your answer 1 = strongly disagree | 2 = disagree | 3 = neither agree nor disagree | 4 = agree | 5 = strongly agree				
16. CULTURAL	a) My clients' families are often involved in decision making and are interested in how to adapt their livestock production systems.				
	1	2	3	4	5
	b) It is important to engage with Aboriginal and Torres Strait peoples to learn new knowledge and practices and exchange knowledge and practices in land management and responsibilities in caring for Country.				
	1	2	3	4	5
	c) Community issues and values on food production are important and influence my clients' choices they make on their properties.				
	1	2	3	4	5
	d) Our local community readily shares knowledge, ideas, and experiences for the good of everyone.				
	1	2	3	4	5
	e) Producers are supportive of each other, and the way livestock production is done in this area.				
	1	2	3	4	5

Transformative Research & Development pathway

The transformative pathway that is to be modelled aims to adapt to a changed climate by adopting and implementing innovations that have been developed through R&D, innovations that are not technically feasible at present. For example, it is assumed that over time it will be possible to use a vaccination delivery for a methane reducing supplement to livestock. We are interested in capturing what else you might consider as transformational change for adapting to a changed climate.

17. What does transformational change look like to you for your clients' production systems? Give examples of change you have seen or implemented yourself that you think represents transformation.

18. What might be the implications from livestock producers transforming their livestock production system in the way that you have described it above ? (e.g. for your advisory business, local community, agricultural sector in your region, livestock industry?)

General

19. How likely are you to advise your clients to consider the “adapt” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already advising
1	2	3	4	5	6

20. How likely are you to advise your clients to consider the “diversify and grow” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already advising
1	2	3	4	5	6

21. How likely are you to advise your clients to consider the “toward carbon neutral” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already advising
1	2	3	4	5	6

22. How likely are you to advise your clients to consider the “transformational” pathway in the future?

extremely unlikely	unlikely	neutral	likely	extremely likely	already advising
1	2	3	4	5	6

23. Describe one or more changes that you have seen your clients already make to manage their production system in response to climate related changes.

24. Describe any future changes your clients are planning for improving the management of their production system in response to climate related changes.

25. What are your key sources of information that you use for keeping yourself informed about climate related changes for your client base? (e.g. internet, social media, printed media, specific consultants, other producers, industry organisations)

26. What advisory knowledge is specific to your region that is not relevant to other places?

27. What do you see as the gaps in current extension and advisory services to support producers in adapting and mitigating climate related change?

28. Please describe any new extension and advisory services that you think are needed for adapting and mitigating climate-related change? (i.e. currently unavailable)

29. List what you think should be the top 3 priorities for research and development project funding over the next five years that will enable adaptation to climate related changes in the livestock industries.

30. Do you have any other comments you would like to make about adapting livestock businesses to climate-related change?

Demographic and advisory service information

31. Age range (place an X in appropriate box)	18-24 years old	
	25-34 years old	
	35-44 years old	
	45-54 years old	
	55-64 years old	
	65-74 years old	
	75 years or older	

32. How many clients do you service?

33. How many years have you been involved in providing advisory services to the livestock industries? **(place an X in appropriate box)**	10 years or less	
	11-20 years	
	21-30 years	
	31-40 years	
	More than 40 years	

34. What are the advisory services that you provide to livestock producers?
