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An indicative assessment of four key areas of climate risk for the 2021 NSW Intergenerational Report

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[1] The views in this paper are those of the authors and do not necessarily reflect those of NSW Treasury. This publication can be accessed from Treasury's website www.treasury.nsw.gov.au.

Acknowledgement

NSW Treasury acknowledges the Traditional Owners of the land on which we live and work, the oldest continuing cultures in human history.

We pay respect to Elders past and present, and the emerging leaders of tomorrow.

We celebrate the continuing connection of Aboriginal and Torres Strait Islander peoples to Country, language and culture and acknowledge the important contributions Aboriginal and Torres Strait Islander peoples make to our communities and economies.

We reflect on the continuing impact of policies of the past, and recognise our responsibility to work with and for Aboriginal and Torres Strait Islander peoples, families and communities, towards better economic, social and cultural outcomes.

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Context

Climate risks are expected to materially impact NSW's long term economic and fiscal outlook. International financial institutions, including credit ratings agencies Moody's and S&P Global, and central banks through the Network for Greening the Financial System, are increasingly considering climate risks as part of their long-term risk assessments. Understanding the potential scale and direction of these impacts will improve the quality of estimates for the 2021 NSW Intergenerational Report (IGR) and contribute to prudent and transparent fiscal management.

Approach

Climate risks to New South Wales' economic and fiscal outlook can be broadly classified into two categories: physical and transitional risks. Physical risks relate to the direct impact of changes in the climate on the economy. 'Transitional risks' refer to the costs and benefits of the economic transition toward lower emissions, for example differences in global coal demand or measures undertaken as part of the NSW Government's commitment to achieve net zero emissions by 2050. This paper focuses on an initial set of physical climate risks, while a separate paper titled *The Sensitivity of the NSW economic and fiscal outlook to global coal demand and the broader energy transition for the 2021 NSW Intergenerational Report*, focuses on an initial set of transitional risks.

The assessment timeframe is limited to the IGR's forty-year projection period. The impact of climate change, particularly under higher warming scenarios, is expected to significantly intensify in the second half of the 21st century, which is outside the IGR's projection period. The results reported in this paper should therefore be interpreted in this context.

This paper sets out an approach to assessing physical climate risks for the NSW Intergenerational Report and deploys this approach with respect to four initial areas of physical climate risk:

1. selected costs of **natural disasters**
2. property and land damage from **sea level rise**
3. the effects of **heatwaves** on workplace productivity
4. the effects of climate change on **agricultural production**.

This is intended to provide an initial analytical framework, evidentiary foundation, and reference case for long-term economic and fiscal risks. This approach provides a foundation that can be extended in the future to cover a broader range of climate risks and deeper analysis of the risks identified in this paper.

Costs associated with these four areas of risk are estimated for three climate scenarios as defined by the Intergovernmental Panel on Climate Change (IPCC). These scenarios represent plausible climate trajectories that reflect global greenhouse gas (GHG) emissions mitigation efforts. They are:

- a 'lower warming' scenario, reflecting climate impacts consistent with the IPCC's Representative Concentration Pathway (RCP) 2.6
- an 'intermediate' scenario, which is used as the reference case, reflecting climate impacts consistent with RCP4.5
- a 'higher warming' scenario, reflecting climate impacts consistent with RCP8.5.

Note that this paper, and NSW Treasury more generally, does not project which climate scenario is more or less likely to transpire. Use of the intermediate warming scenario as the reference case is a technical assumption only. The purpose of the modelling in this paper is to test the sensitivity of the economic and fiscal outlook to differences in the climate scenario, not to forecast the climate scenario itself.

Costs relating to these four risks are applied as shocks to a Computerised General Equilibrium (CGE) model, utilising the intermediate warming scenario as the reference case and aligning this with other research conducted as part of the NSW Intergenerational Report. Relevant shocks are also directly applied to Treasury's Long-Term Fiscal Pressures Model (LTFPM), as are outputs from the CGE model, to assess their fiscal impact. This is aimed at assessing the sensitivity of economic and fiscal outcomes to differences in the climate scenario.

It is important to note that this differs from the approach taken in some previous research on the economic impacts of climate change, such as the 2008 Garnaut Review and the 2020 Deloitte report *A New Choice*, which are directed to the overall costs of climate change. Rather this approach is aligned to emerging best practice in assessing the sensitivity of economic and fiscal outcomes to different climate scenarios, such as recent analysis by the Bank of England.[2]

Projected economic effects are limited to those relating to the four key areas of risk included in the assessment and do not constitute a comprehensive climate risk assessment. These were selected based on two criteria:

1. the likelihood that shocks could materially impact economic or fiscal outcomes within the forty-year projection period
2. a reasonably robust evidence base being available regarding the likely economic or fiscal impacts associated with these shocks.

Projected costs for the four focus areas of risk

Natural Disasters

The risk of natural disasters is projected to increase over the next forty years. With the range dependent on the associated climate scenario:

- Bushfire risk is projected to increase by more than other natural disasters, with the change in risk estimated at between 2 and 24 per cent by 2061.
- Flood risk is projected to increase by between zero and 12 per cent by 2061.

[2] Bank of England, 'The Bank of England's Climate-Related Financial Disclosure 2020'.

- The risk of storms, a category which includes hail and thunderstorms, east coast lows, tropical cyclones and other storms, are projected to increase by between 2 and 5 per cent by 2061. This is entirely driven by an increased risk of tropical cyclones as they continue to encroach further south from Queensland.

The expected annual costs of natural disasters is projected to increase both due to socio-economic factors as well as changes in hazard risk. Expected costs represent a mid-point estimate, with actual costs in any single year being highly variable.

With the range dependent on the climate scenario:

- The expected total economic costs of natural disasters are projected to increase to between $15.8 billion and $17.2 billion (real 2019-20 dollars) per year by 2061, up from $5.1 billion in 2020-21.
- If recent variability in the actual instance of natural disasters was repeated, total economic costs in any single year could range from $30 million to $75 billion (real 2019-20 dollars) under the intermediate warming scenario.
- The expected *direct* economic costs of natural disasters (a subset of total economic costs) are projected to increase from $870 million in 2020-21 to between $2.7 billion and $2.9 billion (real 2019-20 dollars) per year by 2061.
- The expected direct fiscal costs under Disaster Recovery Arrangements (DRA) of natural disasters are projected to increase from $200 million per year in 2020-21 to between $630 million and $700 million (real 2019-20 dollars) by 2061.

Sea Level Rise

Sea level rise is expected to impact NSW through coastal erosion and recession, and tidal inundation. By 2061, between 39,000 and 46,000 properties are estimated to be exposed to coastal erosion or inundation, and annual costs from property damage and loss of land are estimated at between $850 million and $1.3 billion (real 2019-20 dollars) depending on the climate scenario. These costs do not account for the potential for policy interventions, which could include either mitigating damage to existing structures or limiting the exposure of additional structures, for example through development controls. The costs of policy interventions have not been assessed. These estimates also do not include costs associated with damages to infrastructure, or additional costs associated with ensuring the resilience of future infrastructure.

Heatwaves

The instance of heatwaves is expected to increase which is expected to impact workplace productivity. By 2061, between 700,000 and 2.7 million additional days of work are projected to be lost every year due to the higher frequency and intensity of heatwaves. These costs included in this analysis are limited to lost workplace productivity across four sectors for which higher proportions are known to work outdoors: agriculture, construction, manufacturing and mining. This analysis could be further expanded in the future to focus on human health or infrastructure costs.

Changing climate conditions for agricultural production

Agricultural production is expected to be impacted by climate change through changes in rainfall patterns, runoff and temperatures. By 2061, lost production in agriculture based on pastoral and growing conditions is estimated at between $750 million and $1.5 billion (real 2019-20 dollars) depending on the climate scenario. This is in addition to the effect of lost workplace productivity arising from an increase in heatwaves.

Sensitivity of the economic and fiscal outlook to differences in the climate scenario

Differences between climate scenarios are estimated to account for 0.6 per cent of Gross State Product by 2061, and 0.05 of the fiscal gap, measured as the difference between the higher and lower warming scenarios. Realising the lower warming scenario instead of the higher warming scenario would result in additional income in New South Wales of $56 billion (real 2019-20 dollars) over the forty-year projection. This is measured as the net present value of the difference in the size of the New South Wales economy between the lower and higher warmings scenarios using a two per cent discount rate.

The results represent the sensitivity of the economic and fiscal outlook to three climate scenarios, all of which incorporate some degree of warming compared to current conditions. Estimates are limited to the impact of the four areas of risk included in the assessment over the forty-year projection period of the NSW Intergenerational Report. The results should **not** be interpreted as the ‘cost of climate change’.

Areas for future research

Higher priority areas for future extensions of this modelling include water security and drought, and infrastructure construction and maintenance. Additional research areas also include health expenditures, mortality, impacts on tourism, and the impact of climate change on global trade. Extending the projections beyond the IGR’s forty-year forecast period would also increase measured effects given climate scenarios are expected to diverge considerably in the second half of the 21st century.

1. Introduction

The global and Australian climates are changing, with observed changes including increasing air and ocean temperatures and rising sea levels.[3] These trends are projected to continue and intensify over the coming decades, which will have consequences for New South Wales' economic and fiscal outlook. This paper sets out an approach to assessing and modelling physical climate risks, and deploys this to assess the impact of four key areas of climate risk. This will inform the preparation of the *2021* NSW Intergenerational Report, and sits alongside other research papers, most notably *The sensitivity of the NSW economic and fiscal outlook to global coal demand and the broader energy transition for the NSW Intergenerational Report*,[4] which deploys a similar approach to assess a selection of transitional climate risks, and *Projecting Long Run Productivity Growth Rates for the 2021 Intergenerational Report*,[5] which projects long run productivity growth.

Recent events have demonstrated the potential for the climate to impact New South Wales' economic and fiscal position. In 2019-20, economic output in the agricultural sector was the weakest in a decade following a prolonged drought, and the NSW Government spent a record amount on natural disaster relief. Alongside this, credit ratings agencies Moody's and S&P Global have begun accounting for climate risks in their credit assessments,[6] and international financial institutions including the Organisation for Economic Co-operation and Development (OECD) and the International Monetary Fund (IMF), and central banks including the Reserve Bank of Australia,[7] have recommended that governments identify and assess climate risks in order to better set priorities and allocate resources.[8] Focusing on physical climate risks is therefore increasingly necessary for New South Wales to demonstrate its commitment to prudent fiscal management, as required under the *Fiscal Responsibility Act 2012*.

The approach set out in this paper builds on those taken in previous economic assessments including the Garnaut Review in 2008 and by Deloitte in 2020.[9] Computerised General Equilibrium (CGE) modelling is used to assess the overall economic impact of four key climate risks: natural disasters, sea level rise, heatwaves and the impact of changes in the climate on agricultural production.

This is a relatively limited list and the estimation of costs associated with each of these risks is not exhaustive. The approach taken is intentionally conservative. It is aimed at:

- developing a robust climate risk assessment framework
- demonstrating the potential of this framework by utilising it to conduct an initial risk assessment across four key areas.

It is anticipated this framework could be extended in future research to encompass a wider range of climate risks.

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[3] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'; Pearce et al., *Climate Change in Australia*; NSW Office of Environment and Heritage, *Impacts of Climate Change on Natural Hazards Profiles.*
[4] NSW Treasury, 'The Sensitivity of the NSW Economic and Fiscal Outlook to Global Coal Demand and the Broader Energy Transition for the 2021 NSW Intergenerational Report'.
[5] NSW Treasury, 'Projecting Long Run Productivity Growth Rates for the 2021 Intergenerational Report'.
[6] Moody's Investors Services, 'Climate Change & Sovereign Credit Risk'; Kernan et al., 'How Does S&P Global Ratings Incorporate Environmental, Social, And Governance Risks Into Its Ratings Analysis'.
[7] Network for Greening the Financial System, 'NGFS Publishes a First Set of Climate Scenarios for Forward Looking Climate Risks Assessment alongside a User Guide, and an Inquiry into the Potential Impact of Climate Change on Monetary Policy'.
[8] OECD, 'Recommendation of the Council on the Governance of Critical Risks'.
[9] Garnaut, *The Garnaut Climate Change Review*; Deloitte Access Economics, 'A New Choice'.

The distinctiveness of the approach set out in this paper is twofold:

- firstly, CGE modelling is used in combination with Treasury's Long-Term Fiscal Pressures Model (LTFPM) to estimate the fiscal impacts of these risks.
- secondly the modelling assesses the four risks under three climate scenarios:
    - a 'lower warming' scenario, reflecting climate impacts consistent with the IPCC's Representative Concentration Pathway (RCP) 2.6
    - an 'intermediate' scenario, which is used as the reference case, reflecting climate impacts consistent with RCP4.5
    - a 'higher warming' scenario, reflecting climate impacts consistent with RCP8.5.

This contrasts with previous economic analyses which have used a 'no climate change' scenario as their reference case in order to demonstrate the total costs of climate change. Rather, this approach is in line with emerging best practice in climate risk assessments, such as that conducted by the Bank of England.[10] This approach is aimed at ensuring the modelling is focussed on the sensitivity of the NSW economy and budget to variations in the climate trajectory. Given the inherent uncertainties in projecting future climatic conditions, and their potential economic and fiscal impacts, the estimates set out in this paper are indicative only and aimed at demonstrating the potential scope and scale of the challenge.

Chart 1 Illustrative scope of modelling

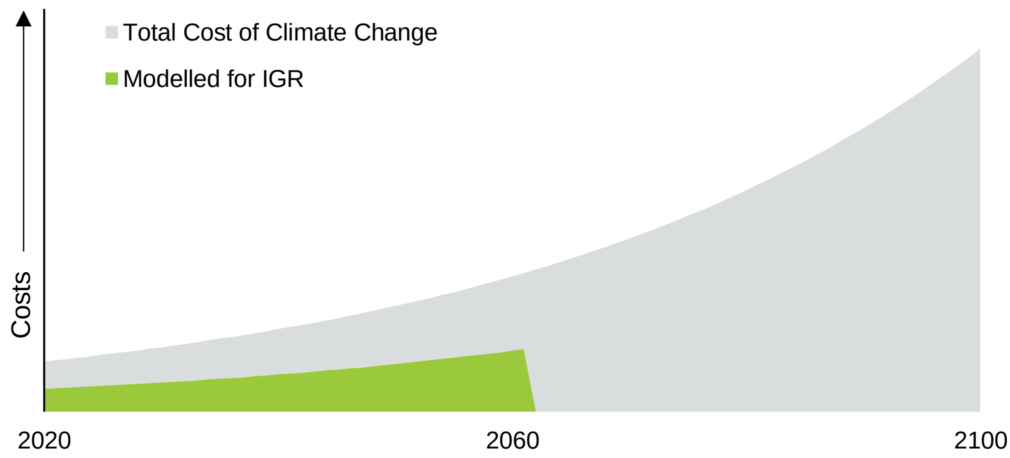

Chart is a conceptual illustration only and is not to scale. Source: NSW Treasury.

Modelling for the NSW IGR is conducted on the underlying assumption that policies remain unchanged over the projection period, which allows for an assessment of the long-term consequences of existing policy settings. Each of the three climate scenarios is therefore assumed to be possible under current policy settings. The impact of transitioning to a lower emissions economy is considered in a separate paper, *The sensitivity of the NSW economic and fiscal outlook to global coal demand and the broader energy transition for the 2021 NSW Intergenerational Report.*[11]

[10] Bank of England, 'The Bank of England's Climate-Related Financial Disclosure 2020'.
[11] NSW Treasury, 'The Sensitivity of the NSW Economic and Fiscal Outlook to Global Coal Demand and the Broader Energy Transition for the 2021 NSW Intergenerational Report'.

2. Context: incorporating climate risk assessment to improve the quality of the IGR's projections

International institutions have recommended jurisdictions undertake more systematic assessment of climate risks

Several international institutions are applying rigorous analysis to estimate the potential for climate risks to impact economic outcomes. The Network for Greening the Financial System (NGFS), a network of central banks that includes the Reserve Bank of Australia, recently urged a more comprehensive consideration of macroeconomic and fiscal risks associated with climate change. This follows a range of journal articles published by the IMF and OECD outlining the benefits of more comprehensively accounting for climate risks in long term fiscal statements.[12] The credit rating agency S&P has recently noted that, "climate change could have significant implications for sovereign ratings in the decades to come."[13] Moody's already explicitly includes climate risks in its evaluation of sovereigns' and sub-sovereigns' ability and willingness to repay their debts,[14] and recently noted that New South Wales is subject to a range of climate-related risks, including acute climate risks such as bushfires and floods and chronic climate risks such as cumulative changes to weather patterns and drought.[15]

The climate is changing

Between 1880 and 2012, global average surface temperatures increased by at least 0.85°C.[16] This is driving a range of other changes to the earth's climate and environment. Over a similar time period, global average sea levels rose by 25cm,[17] and oceans became warmer and more acidic.[18] Rainfall patterns have changed, with more instances of extreme precipitation and a shift in seasonal patterns. There have been more heatwaves, and fewer periods of extreme cold temperature.[19]

Changes in the climate have been observed in New South Wales and Australia. Australia has warmed by 1.44°C since records began in 1910 (see

Chart 2).[20] Satellite observations since 1993 indicate that sea levels off the south eastern coast of Australia have been rising at a faster pace than the global average.[21] There has been a trend toward more dangerous fire weather conditions in New South Wales and an earlier start and overall lengthening of the fire season. There has been a decline in rainfall over winter across much of the State, combined with an increase in the intensity of heavy rainfall events. There have been fewer East Coast Lows, particularly during winter, but those that have occurred have been more intense.[22]

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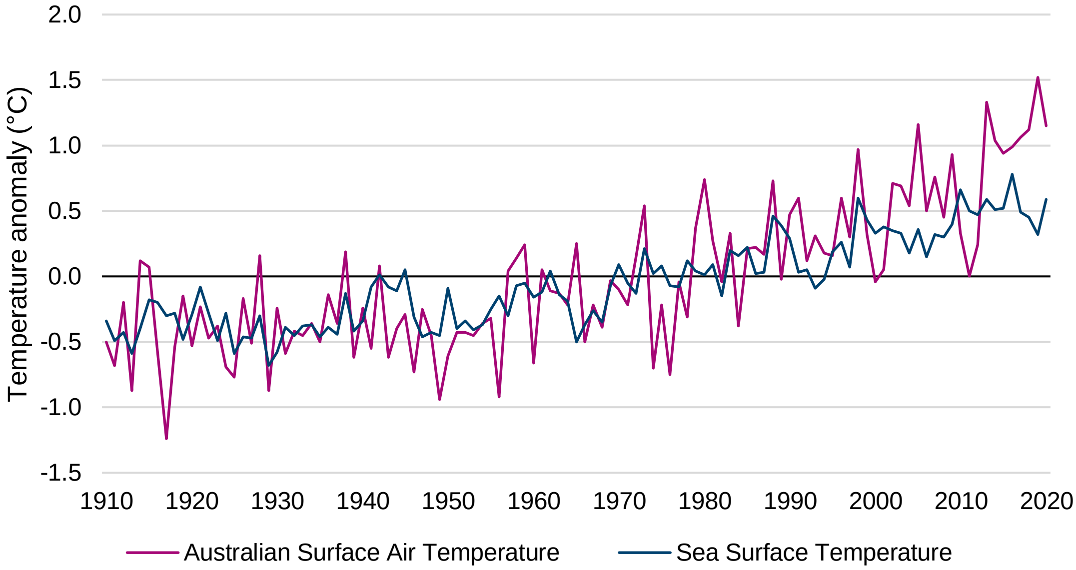
[12] Anderson and Sheppard, 'Fiscal Futures, Institutional Budget Reforms, and Their Effects: What Can Be Learned?'; Cebotari et al., *Fiscal Risks*.
[13] Kernan et al., 'How Does S&P Global Ratings Incorporate Environmental, Social, And Governance Risks Into Its Ratings Analysis'.
[14] Moody's Investors Services, 'Climate Change & Sovereign Credit Risk'.
[15] Moody's Investors Service, 'Issuer In-Depth 29 January 2020: State of New South Wales (Australia) Droughts and Bushfires Materially Increase Budget Pressures and Pose Long-Term Challenges'.
[16] Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*.
[17] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
[18] Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*.
[19] The Intergovernmental Panel on Climate Change (IPCC) summarises the extent of these changes, as at the time of publication, in its Fifth Assessment Report published in 2013.
[20] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
[21] Ibid.
[22] 'Eastern Seaboard Climate Change Initiative'.

Chart 2 Surface and ocean temperatures in Australia

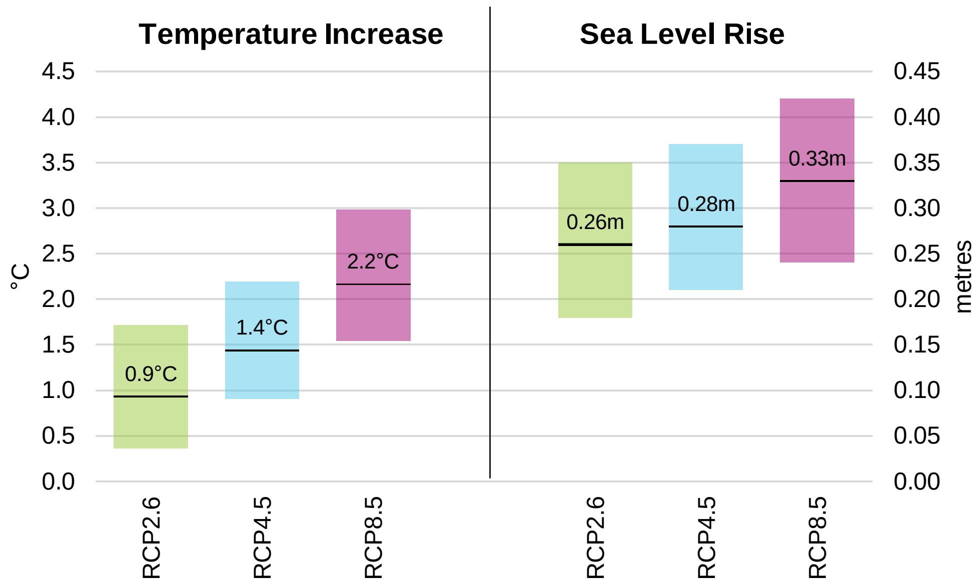


Source: Bureau of Meteorology State of the Climate 2020. Anomolies in mean sea surface temperature, and temperature over land, in the Australian region. Anomalies are the departures from the 1961-1990 standard averaging period. Sea surface temperature values are provided for a region around Australia (4-46°S and 94-174°E).

Changes in the climate are projected to continue

These trends are set to continue, with their trajectories largely tied to the future outlook for global GHG emissions, which in turn is dependent on global policy settings and technological development. In response, the IPCC has developed climate scenarios or "Representative Concentration Pathways" (RCPs), which represent a range of potential emissions and warming trajectories. The widespread adoption of these scenarios has allowed for some consistency and comparability across research into future changes in the climate, and the associated implications.

Chart 3 Temperature Increase and Sea Level Rise Projected for 2060 under selected RCPs



Source: IPCC AR5. Global mean surface temperature increase and mean sea level rise since 1986-2005 average. Bands represent 90 per cent confidence intervals on temperature projections and the 'likely range' (66% confidence) for sea level rise projections.

Projections of global surface temperatures and sea level rise by 2060 for three RPCs are outlined in Chart 3. Under all scenarios, the trends described above are set to continue, with the difference between scenarios primarily being one of scale. Global surface temperatures will continue to increase, sea levels will continue to rise, heatwaves and extreme bushfire weather will further intensify and rainfall patterns will continue to shift.

The changing climate has already impacted New South Wales fiscal and economic position

Risks associated with climate change have already had a range of impacts on New South Wales' fiscal and economic position. The 2019-20 bushfire season was the most economically damaging on record, resulting in at least $1.8 billion in direct economic damages (as measured through insurance losses)[23], and $4.4 billion[24] in fiscal costs over five years to 2023-24 (including $1.1 billion measured through Disaster Recovery Funding Arrangements).[25] Drought conditions affecting much of New South Wales since 2016 had a significant impact on agricultural output and also directly impacted the fiscal position in the form of drought relief payments, made via the NSW Rural Assistance Authority. Ongoing changes in rainfall levels and patterns have affected water security in both metropolitan and regional areas, bringing with them economic impacts and fiscal obligations, including the requirement to build and maintain water infrastructure. As long as these climactic trends continue, their effects on fiscal and economic outcomes can be expected to persist.

Climate risks have not previously been considered for the NSW Intergenerational Report

NSW Intergenerational Reports have to date focused on the "Three Ps" of economic growth: population, participation and productivity. These have been modelled using NSW Treasury's LTFPM, which projects the incidence of any long term 'fiscal gap'. The LTFPM projects specific areas of

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[23] Insurance Council of Australia, 'Catastrophe Data' NSW Data only.
[24] Some of this is shared with the Commonwealth.
[25] NSW Treasury, '2020-21 Budget'.

revenue and expenditure by combining economic and demographic projections, derived through the "Three Ps" framework, with analysis of historical trends. This approach remains the basis of the IGR and is well suited to evaluating the impact of changing demographics – most notably the ageing of the population – on long-term fiscal outcomes.

The purpose of the NSW Intergenerational Report has evolved and broadened over time, beyond the traditional focus on population ageing to other structural trends and system dynamics. The 2016 NSW IGR featured the first major expansion of the LTFPM beyond the "three Ps" framework, with explicit modelling of the housing market. This is in recognition of the importance of housing-related revenue items to fiscal outcomes and was the result of research which linked the housing market with interstate and overseas migration. It enabled the 2016 IGR to include detailed analysis of the housing market, and its role as a key determinant of the State's long-term fiscal position.

To date, however, the LTFPM has not explicitly considered how risks relating to climate change might impact fiscal outcomes. In particular, the sensitivity of economic and fiscal projections to different climate trajectories has not been addressed.

3. Approaches to economic and fiscal climate risk assessments

Fiscal assessments

Few jurisdictions across the world have incorporated climate risks into long term fiscal modelling, despite recommendations over the past decade from international economic and financial institutions. One of the more comprehensive assessments of physical fiscal climate risks was undertaken for the United States by the White House Office of Management and Budget in 2016.[26] This report focused on estimating fiscal costs associated with four key risks under an unmitigated climate scenario (RCP8.5). The risks assessed were coastal storms, agricultural production, wildfire management and air quality. Economic risks were also accounted for through reference to previous studies, without being explicitly modelled.

In the UK, the Office of Budget Responsibility (OBR) included a chapter on climate change in its 2019 *Fiscal Risks Report*, although this did not include systematic modelling. The OBR intends to further develop climate modelling in the future in partnership with the OECD and NFFS. A similar qualitative approach has been taken by a range of other jurisdictions in their long-term fiscal statements including Ireland[27] and New Zealand.[28]

Economic assessments

Economic assessments have generally separated climate risks into two categories:

- physical risks which arise directly from changes in the climate
- transition risks which arise from efforts to reduce GHG emissions.[29]

In Australia, the Commonwealth Government reported the findings of economic modelling on both the physical and transition risks of climate change in its 2010 Intergenerational Report, although this did not explicitly consider fiscal risks. The modelling was conducted for the Garnaut Review, which utilised a CGE model (specifically the Monash Multi Regional Forecasting Model or MMRF[30]) to estimate the aggregate economic impact of a range of climate shocks under different climate scenarios. A similar approach was used by Deloitte in research published in November 2020.[31] Both of these approaches considered purely physical risks by modelling an 'unmitigated' climate scenario, before including other 'mitigation' scenarios which blended transition risks with an associated reduction in physical risks. There are some difference in the estimated scale of impacts arising from physical risks across these two assessments – Garnaut estimated a 2.1 per cent reduction in Australian GDP by 2050 compared to a 3.6 reduction forecast by Deloitte. Both analyses agreed New South Wales will likely be less impacted than other States: Deloitte estimated New South Wales

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[26] Office of Management and Budget, '2016 Draft Report to Congress on the Benefits and Costs of Federal Regulations and Agency Compliance with the Unfunded Mandates Reform Act'.
[27] Irish Fiscal Advisory Council, 'Long-Term Sustainability Report: Fiscal Challenges and Risks 2025-2050'.
[28] New Zealand Treasury, 'He Tirohanga Mokopuna: 2016 Statement on New Zealand's Long-Term Fiscal Position'.
[29] Note that there are both costs and benefits involved in reducing greenhouse gas emissions. The term 'transition risks' is commonly used (for example by the NGFS) to refer to the process of greenhouse gas reduction, but does not imply that this process involves only downside risks. This is more fully explored in NSW Treasury, 'The Sensitivity of the NSW Economic and Fiscal Outlook to Global Coal Demand and the Broader Energy Transition for the 2021 NSW Intergenerational Report'.
[30] Adams et al., 'MMRF: Monash Multi-Regional Forecasting Model: A Dynamic Multi-Regional Model of the Australian Economy'.
[31] Deloitte Access Economics, 'A New Choice'.

Gross State Product would be 2.2 per cent lower in 2050 under an unmitigated climate scenario while Garnaut estimated the impact at around 1.5 per cent.[32]

At a global level the NGFS has set out a range of scenarios encompassing both physical and transition risks. They projected a global decline in GDP of up to 25 per cent under the 'hot house world' scenario (RCP8.5), which encompasses only physical risks, and then compared this with two mitigation scenarios, both of which incurred transition costs, but resulted in lower costs associated with physical risks. Kompas et. al. used a similar approach to that taken in Garnaut and Deloitte, albeit focused only on physical risks.[33] They applied a range of shocks representing physical risks to a CGE model at a global level to estimate the potential benefits of global compliance with the Paris Agreement that will limit warming to 2°C (RCP4.5).

The IPCC notes the key limitation present in economic assessments of the costs of climate change is that they are necessarily "partial and affected by important conceptual and empirical limitations."[34] That is, these estimates typically underestimate total costs due to limitations in data, difficulties in monetising particular impacts such as biodiversity loss and difficulties accounting for events with low probability but very high impact, including tipping point events, that may occur outside typical modelling timescales.[35]

[32] Note this figure was obtained through visual inspection of charts included in the Garnaut Review (technical paper 5, p. 13).
[33] Kompas, Pham, and Che, 'The Effects of Climate Change on GDP by Country and the Global Economic Gains From Complying With the Paris Climate Accord'.
[34] Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*, 79.
[35] The Garnaut Review labelled these Type 2, 3 and 4 costs respectively.

4. Approach to assessing climate risks

Overview

The approach set out in this assessment draws on previous approaches to estimating both economic and fiscal impacts of climate change. This paper sets out an approach to assessing physical risks while transitional risks are considered separately in *The sensitivity of the NSW economic and fiscal outlook to global coal demand and the broader energy transition for the 2021 NSW Intergenerational Report*.[36]

The approach considers three climate scenarios (outlined below). A set of 'shocks' are applied to a CGE model (the Victoria University Regional Model or VURM[37]), with each shock reflecting the estimated impact of key areas of climate risk under each scenario. This will provide information on the potential impact and scale of these risks to the NSW budget and economy. The output from the CGE model will then be applied to Treasury's LTFPM, along with some direct fiscal estimates where relevant. This enables an assessment of the sensitivity of economic growth estimates to different climate scenarios.

This section will first contextualise this line of research with reference to a range of other research modules being conducted for IGR. This is followed by a description of the three climate scenarios, and the associated selection criteria for the initial set of shocks included in this modelling. These scenarios and shocks are presented regarding their application to the VURM CGE model itself. Lastly, a range of further modelling extensions are listed to provide direction for further research.

Scenarios

This paper forms one component of a series of research papers being released in advance of the NSW Intergenerational Report. Publicly releasing these papers ensures that information is available on how NSW Treasury considers the key components of the NSW Treasury LTFPM, which underpins the IGR. These research papers cover a range of topics including population (encompassing overseas and interstate migration as well as fertility), labour market participation and productivity growth. These form the core 'Three Ps' framework and are the key input components for the LTFPM. Combined they yield sufficient information to facilitate the projection of long run economic growth.

In addition to these, Treasury has also conducted research into some of the most critical factors likely to impact the State's long-term fiscal and economic position. Topics covered in these papers include long-term health expenses, the housing market under COVID and secular stagnation, as well as initial assessments of a selection of physical and transitional climate risks.

There is overlap between these research topics: specifically, there are factors associated with climate change that impact economic growth, primarily through impacts on productivity. However, as noted in the NSW Treasury research paper *Projecting Long Run Productivity Growth Rates for the 2021 Intergenerational Report*,[38] productivity growth depends on a range of factors, including the pace and scope of economic reforms, technological development, the industry structure of the economy, demographics, the distribution of income and wealth and geopolitical concerns. It is feasible that

[36] NSW Treasury, 'The Sensitivity of the NSW Economic and Fiscal Outlook to Global Coal Demand and the Broader Energy Transition for the 2021 NSW Intergenerational Report'.
[37] More details of this are in the technical appendix.
[38] NSW Treasury, 'Projecting Long Run Productivity Growth Rates for the 2021 Intergenerational Report'.

detailed research into each of these would yield conclusions regarding their impact (positive or negative) on productivity growth. Indeed, the productivity paper endeavours to weigh these factors and concludes that on balance risks tend toward on the downside. Ultimately, however, the NSW Treasury productivity technical paper decides against using a 'building block' approach, and instead project productivity growth to eventually return to a long-run historical average, which yields 1.3 per cent annual productivity growth.[39]

This approach to projecting productivity growth is relevant for setting the key assumptions underlying climate scenarios in this paper. Common practice in previous research has been to assume a baseline 'no climate change' scenario, then impose shocks to derive a 'climate change' scenario, in which economic growth, and hence implicitly productivity growth, is lower. This approach is not, however, consistent with the method used to project underlying productivity growth outlined in the productivity technical paper. Given the preferred method based on an historical average, rather than taking a 'building block' approach that looks at the component drivers of productivity, it is not methodologically possible to make modifications to a specific component, such as climate change, let alone the limited range of physical climate risks assessed in this paper.

It should be noted that the purpose of this research paper is not to project long run economic growth. Rather, it is to set out an approach that can be used to assess areas of climate risk and utilise this to assess an initial set of risks, including the degree to which these vary under different global climate scenarios. For these reasons, the approach developed in this paper operates within the baseline 'Three Ps' assumptions adopted elsewhere in Treasury research, incorporating each of these into the reference case.

Accordingly, the estimates presented in this paper should be interpreted as the sensitivity of the economic and fiscal outlook to differences in the climate scenario. They are generally applicable to alternative estimates of long run economic growth. For example, an alternative estimate as to the productivity outlook for the central case of RCP4.5 may not assume that productivity growth continues on its 30-year historical trend, but may instead use a lower assumption based on the potential impacts of climate change under any warming scenario compared with the 30-year historical trend.

A further constraint is that ultimately the IGR is required to provide a single projection of the fiscal gap. This presents a challenge for estimating climate risks because the global emissions trajectory is highly dependent on global policy decisions and technological development in the decades to come. This is why the IPCC sets out a range of scenarios (RCPs), without specifying any one scenario as the 'most likely' outcome.

The three climate scenarios considered in the modelling are:

- a 'lower warming' scenario, reflecting climate impacts consistent with RCP2.6
- an 'intermediate' scenario, reflecting climate impacts consistent with RCP4.5
- a 'higher warming' scenario, reflecting climate impacts consistent with RCP8.5.

The intermediate scenario will act as the reference case for the CGE model and will adopt the 'Three Ps' assumptions outlined in separate Treasury research papers. This is a technical assumption and does not imply that Treasury has formed a view as to which RCP is more likely: it has not. This, as well as the inclusion of only a limited range of climate risks, means the findings are not directly

[39] This is lower than the 1.5 per cent assumed in the 2016 IGR reflecting weaker productivity growth in recent years.

comparable to previous analyses, such as those by Deloitte and the Garnaut Review, which have aimed at putting a ‘cost’ on climate change and have assessed a broader range of risks. The benefit of the approach outlined here is that the *spread* between the higher and lower warming scenarios will be broadly representative of the *sensitivity* of economic and fiscal outcomes with respect to different emissions trajectories. The modelling results presented in this paper also limit the scope of this climate sensitivity to the initial set of climate risks included in the modelling.

NSW Policy Settings, GHG Emissions and Climate Outcomes

This paper focuses on a range of key physical risks associated with climate change, with the implicit assumption that these occur outside the control of the NSW Government. To a large degree this is true: New South Wales is responsible for less than 0.4% of global emissions,[40] hence even if emissions were cut to zero tomorrow in New South Wales, in lieu of changes in other jurisdictions the impact on global climate outcomes would be minimal.

The NSW Government, however, aims to achieve net zero emissions by 2050, along with every other Australian State and Territory, and a growing list of other countries. Achieving this target will likely entail significant changes in the production model of many industries, as well as the overall structure of the economy itself. These changes are likely to be driven by technological development as well as local and global policy settings. Therefore, even with the IGR’s underlying assumption of ‘no policy change’ a range of climate scenarios are well within scope.

A separate research paper, also being developed for the IGR, will assess the potential economic and fiscal impact of the pace of transition in the NSW energy sector.[41] Modelling physical risks and transition risks separately provides more granular information on to the impact of specific elements on the economy and budget and provides more flexibility in how these findings can be used for policy making. Analysis incorporating the findings of both papers, as well as other research units, will be brought together in the IGR itself.

[40] Treasury calculation based on information contained in NSW Department of Planning, Industry and Environment, ‘Net Zero Plan. Stage 1: 2020-2030’.
[41] NSW Treasury, ‘The Sensitivity of the NSW Economic and Fiscal Outlook to Global Coal Demand and the Broader Energy Transition for the 2021 NSW Intergenerational Report’.

5. Projected impacts of key areas of climate risk: natural disasters, sea level rise, heatwaves and climatic effects on agricultural production

Shock Selection

The potential range of climate-related economic shocks (both acute and chronic) is vast and encompasses minor impacts on specific sectors as well potentially catastrophic tipping-point events. The intention of this assessment is not to model a full range of shocks – this would be impractical due primarily to uncertainty regarding their scale and timing. The IGR's forty-year projection timeframe further limits the potential scope of the analysis. The modelling is instead focused on piloting an approach to climate risk assessment and demonstrating the usefulness of this approach by deploying it for an initial set of shocks. Shock selection is based on:

1. the likelihood that shocks could materially impact economic or fiscal outcomes within the forty-year projection period
2. a reasonably robust evidence base being available regarding the likely economic or fiscal impacts associated with these shocks.

The second of these criteria requires some further elaboration. There are layers of uncertainty with regards to how changes in the global climate will impact regional economic and fiscal conditions in New South Wales. For a given global climate scenario, different climate models can sometimes provide conflicting projections of how regional and local climates will be impacted. This uncertainty is heightened for acute climate impacts such as natural disasters which occur due to the complex interaction of a series of factors. Even if climate and weather conditions were known, there is then further uncertainty regarding their potential economic and fiscal impacts. The shocks selected for inclusion in this paper are those which data is relatively reliable regarding both the likely regional climate impacts, as well their likely economic or fiscal costs. Even with this more limited set of shocks, there remains considerable complexity which has not been modelled, hence the projections should be considered indicative only.

This approach ensures the modelling will provide meaningful information about *how* and *why* the selected areas of climate risk are likely to impact New South Wales' long-term fiscal position. It also provides an indication of the *scale of impact* of these areas of risk against specific revenue or expenditure lines, as well as for the economy overall. By focusing only on a subset of specific and measurable risks, this analysis does not provide an estimate of the total economic and fiscal impacts of climate change. Even with future extensions of this modelling to include a broader range of risks, any assessment will inevitably be only partial. As noted by the IPCC, this is essentially unavoidable.[42]

Using the above criteria, the key shocks to be applied to the model are:

1. some of the fiscal costs and direct economic damages of natural disasters
2. property and land damages from sea level rise
3. the impact of heatwaves on workplace productivity
4. the effects of climate on agricultural production.

[42] Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*.

A final note of caution: it is not possible to definitively model how future changes in the climate will be realised on a global or regional level. Climate models often provide differing projections even given the same input data. Ideally projections would be based on the output of multiple models, however this has not been possible for some of the estimates outlined below. The estimated shocks are therefore indicative only. Further information on the modelling approach is available in the technical appendix.

Natural Disasters

Increase in frequency, intensity and duration of a range of natural disasters

The frequency, intensity and duration of a range of natural disasters is projected to increase in the future, including the those with, historically, the costliest impacts on New South Wales: bushfires, flooding, and storms.[43] The bushfire season is projected to lengthen and there are expected to be more days of extreme fire danger.[44] Rainfall patterns are expected to change, with effects including more intense extreme rainfall events,[45] and tropical cyclones are projected to continue to track further south from Queensland.[46] This section outlines how climate change is projected to impact the economic and fiscal costs of natural disasters in New South Wales over the next forty years.

Economic and Fiscal Impact

Natural disasters can have very significant economic, fiscal and social impacts – the 2019-20 bushfire season is a high-profile recent example. For communities, livelihoods can be disrupted through damage to homes and other property, disruption to communities, services and businesses, impacts on physical and mental health, and in some instances, fatalities.[47] These economic, social and fiscal costs can be significant in aggregate, with some impacts still felt months and years after the disaster event itself.

Governments have a range of responsibilities relating to natural disasters including in coordinating and delivering the emergency response, providing individuals and businesses with financial and other assistance, ensuring continuity of service delivery and funding and coordinating the clean-up and recovery, including restoration of damaged infrastructure and public lands.[48] The NSW Government provides ongoing funding to emergency response agencies including the Rural Fire Service (RFS) and the State Emergency Service (SES). Jointly with the Commonwealth, it also provides additional 'surge' funding to declared natural disasters through the Disaster Recovery Funding Arrangements (DRA).[49]

From the NSW Government's perspective there is also some policy risk, with a range of reviews at the Commonwealth level proposing changes to funding arrangements, which could have significant

[43] Insurance Council of Australia, 'Catastrophe Data'.
[44] CSIRO, 'The 2019-20 Bushfires'.
[45] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
[46] Bruyere et al., 'Severe Weather in a Changing Climate (2nd Edition)'.
[47] UN Office on Disaster Risk Reduction, '"Staggering" Rise in Climate Emergencies in Last 20 Years, New Disaster Research Shows'.
[48] Australian Government Department of Home Affairs, 'Disaster Recovery Funding Arrangements 2018'.
[49] These replaced the Natural Disaster Relief and Recovery Arrangements (NDRRA) from October 2018 and are referred to interchangeably throughout this paper. Cost sharing arrangements are set out in Australian Government Department of Home Affairs.

implications for the NSW budget.[50] Modelling the economic and fiscal costs associated with natural disasters will assist in quantifying the potential scale of these risks.

Projecting Natural Disaster Costs

The process for projecting future natural disaster costs involves:

1. specifying which costs are within scope
2. estimating the current expected level of these costs
3. projecting expected costs in the absence of climate change
4. estimating additional costs arising from increased climate risks.

Costs within scope

This analysis focuses on three measures of the costs of natural disasters:

a. direct economic costs as measured through the value of insurance losses
b. direct fiscal costs as measured through annual NSW Government DRA returns
c. overall economic costs, incorporating direct, indirect and intangible costs.

The choice of which items to include when accounting for the costs of natural disasters depends on both the purpose of the analysis and data availability. Analyses of total economic welfare, such as that undertaken by Deloitte in *The costs of disasters in our States and Territories*,[51] cover a broad range of costs. These include both conventional economic measures such as direct and indirect economic costs, and intangible factors such as physical and mental health, statistical measures of the value of human life, and other non-market factors such as wilderness and biodiversity loss. Including these factors is appropriate – even desirable – when considering total economic and social welfare withing frameworks such as cost benefit analysis.

The IGR is focused on conventional economic indicators such as Gross State Product and components thereof, and other factors impacting NSW Government revenue and expenditure. This means intangible costs are outside the scope of estimates relating to the Fiscal Gap. Therefore, the core modelling will utilise only estimates direct economic and fiscal costs. However, estimates of the total economic cost of natural disasters will also be presented in this paper, to assist in better understanding the overall impact of natural disasters on economic welfare, as well as the overall impact of changes in climate risk.

Box 1 describes some of the key indirect and intangible costs which are not included in estimates of direct economic or fiscal costs but are included in estimates of total economic costs.

[50] Royal Commission into National Natural Disaster Arrangements, 'Royal Commission into National Natural Disaster Arrangements Report'; Productivity Commission, 'Natural Disaster Funding Arrangements, Inquiry Report Volume 1'.
[51] Deloitte Access Economics, 'Building Resilience in Our States and Territories'.

Box 1: Indirect and Intangible Costs of Natural Disasters

Mortality, Physical and Mental Health

Natural disasters can cause significant physical and mental health impacts. Between 1967 and 2020 natural disasters in Australia are estimated to have directly caused more than 1,400 deaths and over 7,000 injuries.[52] A recent study estimated health costs associated with bushfire smoke amounted to $1.9 billion in 2019-20 including $1.1 billion in New South Wales.[53] 98.7 per cent of these costs in 2019-20[54] relate to the intangible costs of 429 premature deaths, with the remaining 1.3 per cent relating to the costs of hospital admissions and attendances at Emergency Departments.

Natural disasters can also have severe impacts on the mental health of those living in impacted communities,[55] with significant numbers experiencing mental health problems in the months or even years following the initial event.[56] This can have far reaching and long lasting damage on communities, with some research indicating that anxiety can persist throughout the lifetimes of children exposed to natural disasters.[57]

Aboriginal cultural heritage

Destruction from natural disasters goes beyond just physical damage and can permanently impact Aboriginal cultural heritage. For example, the 2019-20 bushfires potentially impacted thousands of significant cultural sites representing tens of thousands of years' history. Sites at risk include trees that have been modified for cultural use, rock art and engravings, stone-tool sites and grinding stones.[58]

Biodiversity and wilderness loss

Natural disasters can impact the natural environment in ways that have little if any impact on conventional economic indicators. For example, the 2019-20 bushfires are estimated to have burned 5.4 million hectares across New South Wales, representing 37 per cent of all NSW national park estate and 42 per cent of NSW state forest. 25 per cent of suitable Koala habitat was burned; 293 threatened animal species have been sighted in areas burned by fire, as have 680 threatened plant species. Since 2013 fires have resulted in a 39 per cent reduction in the ecological carrying capacity in the fire ground.[59]

Disruption to businesses and tourism

Natural disasters can cause significant economic disruption to businesses in impacted communities. Even where businesses are not directly impacted, natural disasters can upend communities in ways that make it difficult or even impossible for businesses to operate. The 2019-20 bushfire season severely impacted tourism in fire-hit communities. For the hard-hit NSW

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52 'EM-DAT Database'.
53 Johnston et al., 'Unprecedented Health Costs of Smoke-Related PM 2.5 from the 2019–20 Australian Megafires'.
54 At a national level – the specific breakdown was not provided at a state level.
55 Ingle and Mikulewicz, 'Mental Health and Climate Change'; Cianconi, Betrò, and Janiri, 'The Impact of Climate Change on Mental Health'.
56 Bryant et al., 'Psychological Outcomes Following the Victorian Black Saturday Bushfires'.
57 McFarlane and Hooff, 'Impact of Childhood Exposure to a Natural Disaster on Adult Mental Health'.
58 Pickrell, 'Thousands of Ancient Aboriginal Sites Probably Damaged in Australian Fires'.
59 NSW Department of Planning, Industry and Environment, 'NSW Fire and the Environment 2019-20 Summary: Biodiversity and Landscape Data and Analyses to Understand the Effects of the Fire Events.'

South Coast, tourism constitutes 11 per cent of the local economy.[60] Furthermore the scale of this event, and extent of global media coverage, could cause long-lasting reputational damage to New South Wales and Australia in international tourist markets.[61] Data limitations constrain the reliable estimation of the indirect economic costs of natural disasters for businesses and tourism, particularly given the need to account for displacement of economic activity.[62]

Chronic climate risks and compounding impacts

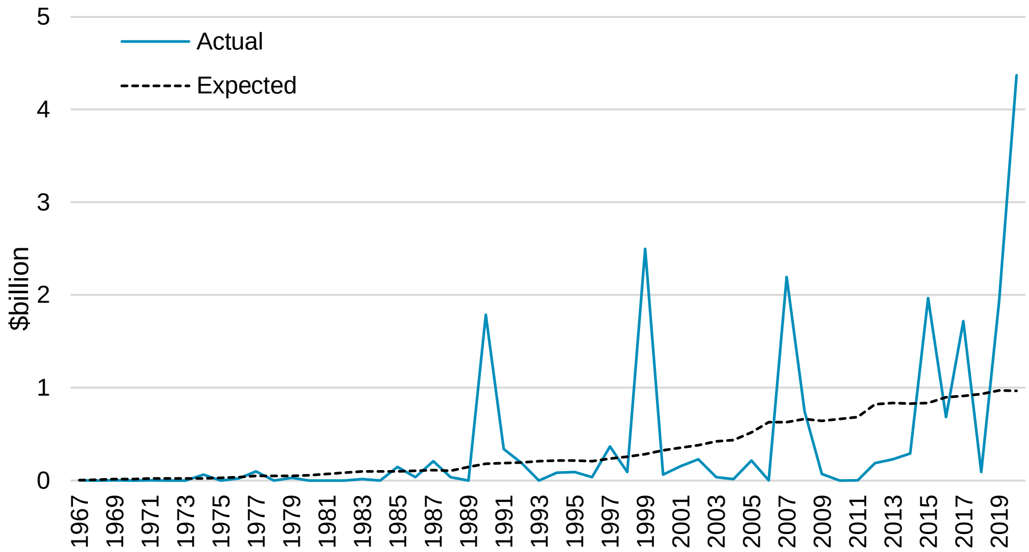
The impacts of natural disasters can be exacerbated through compound impacts of chronic climate risks, or the incidence of multiple natural disasters in relatively quick succession. Research outlined in the IAG report *Severe Weather in a Changing Climate – 2nd Edition*, indicates that the coincidence of multiple natural disasters can increase the severity of impact of natural disasters, by more than the sum of individual impacts.[63] A cascading series of events can exacerbate mental health impacts, and complicate recovery efforts. The South Coast was subject to a series of natural disasters through 2019-20, including drought, catastrophic bushfires, flooding and COVID-19. There is also some emerging evidence that climate change could increase the likelihood of multiple interconnected events occurring in close proximity.[64]

Expected vs actual natural disaster costs

Before setting out the projection method, it is important to delineate between *expected* costs and *actual* costs. Expected costs are essentially a mid-point estimate of the total cost of natural disasters in any given year. The actual incidence of natural disasters is extremely volatile. *Actual* costs in any given year are therefore likely to vary, at times highly significantly, from expected costs. For example, in 2019-20 actual direct economic costs have been estimated at $4.4 billion and direct fiscal costs are estimated at $1.1 billion, far above the expected levels based on long-term averages. Chart 4 compares expected natural disaster costs with actual natural disaster costs in each year.

[60] Including both direct and indirect contribution 'Regional Tourism Satellite Accounts | Tourism Research Australia'.
[61] Judd, '"The World Is Utterly Perplexed": As Australia Burns, Is Our Reputation at Risk?'; Duran, '"They Told People Not to Come"'.
[62] In general, disruption to businesses, including tourism businesses, other than direct clean-up costs, are excluded from analyses of the total costs of disasters.
[63] Bruyere et al., 'Severe Weather in a Changing Climate (2nd Edition)', 94–95.
[64] Bruyere et al., 96.

Chart 4 Actual vs Expected NSW Direct Economic Natural Disaster Costs



Source: NSW Treasury

Historically, a small number of events account for the vast bulk of costs: the top five most expensive events in terms of normalised insured losses accounted for 44 per cent of the NSW total between 1967 and 2020, with 118 other events accounting for the remaining 56 per cent. It is not possible to predict this random component of natural disasters, hence projecting expected costs provides an indication of the relative economic significance of natural disasters only over the medium to long-term, rather than a near-term forecast window. This is reflected in the high degree of variance between expected and actual economic costs in any given year.

Current expected natural *disaster costs*

Current *expected* natural disasters costs are assumed to be an average of historical natural disaster costs, adjusted to account for growth in the economy and population. The scope for any given natural disaster to cause economic damage is ultimately related to the size of the economy itself. Adjusting for this, known as 'normalisation', is a process commonly used by insurers and others conducting major assessments of the costs of natural disasters[65] to facilitate comparisons over time. Total economic costs are estimated by assuming they are proportionate to recorded insurance losses. The technical appendix includes further details of how expected annual natural disaster costs have been calculated.

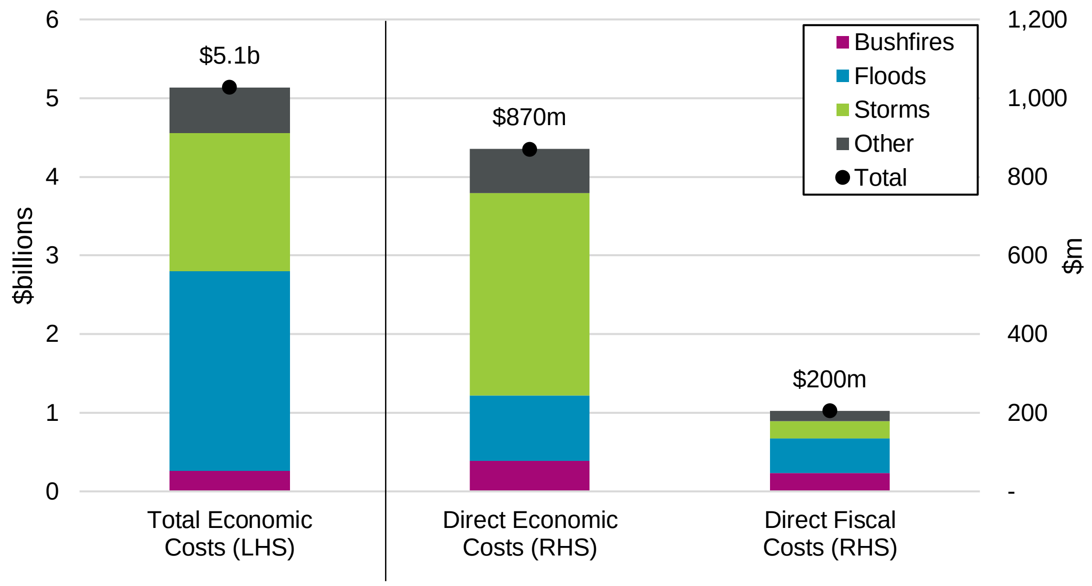
Using this method, expected natural disaster costs in 2020-21 are estimated to be $5.1 billion in total economic costs, including $870 million in direct economic costs. Expected direct fiscal costs under the are estimated at $200 million.[66] Chart 5 provides a breakdown of how this was allocated across the main natural disaster types: bushfires, floods and storms, and other which primarily incorporates

[65] Productivity Commission, 'Natural Disaster Funding Arrangements, Inquiry Report Volume 1'; Deloitte Access Economics, 'Building Resilience in Our States and Territories'.

[66] Figures are rounded. Note this measure of fiscal costs is limited to only that recorded through Disaster Recovery Arrangements returns and is shared with the Commonwealth. This is only a portion of total disaster costs – for example the 2020-21 NSW Budget outlines that $4.4 billion was spent in relation to the 2019-20 bushfires, only $1.1 billion of which is recorded in DRA returns. These additional costs are not within the scope of this initial assessment due to limited availability of consistent data, but would be an obvious candidate for future extensions of this work.

earthquakes. Around half of total economic costs related to floods, and another third related to storms (which incorporates hail and thunderstorms, east coast lows, tropical cyclones and other severe weather). By comparison, bushfire activity contributed relatively little to expected total economic damage. Around half of expected fiscal costs were associated with floods, which can cause extensive damage to infrastructure such as roads, with the remainder split relatively evenly between bushfires and storms.

Chart 5 Expected cost of natural disasters in NSW 2020-21



Source: NSW Treasury estimates. Figures are rounded.

Projected Natural Disaster Costs

Projecting the future costs of natural disasters must account both for economic and population growth, which increases the potential damage that can be inflicted by natural disasters, and any increase in the risk of natural disasters that are generally attributable to climate change. In line with previous assessments,[67] the first component is assumed to be proxied by growth in Gross State Product. Estimating how changes in the climate will affect the risk of specific natural hazards is based on modelling conducted by XDI Pty Ltd,[68] and informed by additional quantitative and qualitative evidence. Note it is assumed climate change will not change the risk of the 'other' category which primarily comprises earthquakes. Further details of the projection method are included in the technical appendix.

Under the reference case, by 2061 the risk of bushfires is projected to increase by 17 per cent, flood risk is projected to increase by 6 per cent by 2061 and the risk of storm damage is projected to increase by 3 per cent compared with current conditions. As expected, bushfire and flood risks increase with higher warming.

[67] Productivity Commission, 'Natural Disaster Funding Arrangements, Inquiry Report Volume 1'.
[68] XDI have expertise in modelling climate risks. Their services have been used by multiple governments in Australia and their modelling underpins other major climate research including Deloitte's recent assessment of climate risks.

Table 1 Change in natural disaster risks between 2020 and 2061

Disaster Type	Change in Risk by 2061		
	Lower Warming (RCP2.6)	Reference Case (RCP4.5)	Higher Warming (RCP8.5)
Bushfires	+2%	+17%	+24%
Floods	-	+6%	+12%
Storms	+2%	+3%	+5%
Other	-	-	-

Source: NSW Treasury estimates. Figures have been rounded.

A caution in interpreting these projections: ultimately natural disasters occur due to the complex interaction of an array of factors. While modelling has accounted for some of these, it is not possible to account for all of them, and there will always be significant uncertainty in those that have been modelled. Hence the estimates presented are indicative only. The approach is intentionally conservative with qualitative evidence suggesting risk factors may increase by more than those estimated for this assessment.

Combining both the socio-economic and climate risk projections, total natural disaster costs under each climate scenario are set out in Table 2. By 2061 the annual expected total economic cost of natural disasters is projected to be between $15.8 billion and $17.2 billion per year by 2061 (real 2019-20 dollars), depending on the climate scenario. This includes direct economic costs of between $2.7 billion and $2.9 billion per year. Expected direct fiscal costs under the DRA are projected to be between $630 million and $700 million per year. Growth in costs is primarily driven by socio-economic factors, although differences in the climate scenario account for variance of up to $1.3 billion in total economic costs per year (calculated as the difference between the higher and lower warming scenarios).

As noted earlier, the actual annual cost of natural disasters will reflect great variability. As an illustrative example, if the volatility of the past 10 years was repeated in the 2050s, actual annual total economic costs by 2061 would range from $30 million to $75 billion under the reference case of intermediate warming, the latter of which would be equivalent to 6 per cent of Gross State Product. Annual direct fiscal costs under the DRA would range from $210 million to $4 billion.

Table 2 Expected Annual Natural Disaster Costs by 2060-61 (real 2019-20 dollars)

		Total Economic Costs	Direct Economic Costs[69]	Direct Fiscal Costs under the DRA	Annual Growth in Nominal Fiscal Costs[70]
2020-21		$5.1b	$870m	$200m	
2060-61	Lower Warming	$15.8b	$2.7b	$630m	5.3%
	Reference Case	$16.5b	$2.8b	$670m	5.5%
	Higher Warming	$17.2b	$2.9b	$700m	5.6%

Source: NSW Treasury. Total economic costs are not included in CGE modelling.

Sea Levels

Rising sea levels

Sea levels are rising through thermal expansion of the oceans and the melting of ice sheets. Since the late 19th century average global sea levels have risen 25cm,[71] with half this occurring since 1970. Furthermore the rate of sea level rise off the southeast of Australia has been significantly higher than the global average.[72] Over the coming decades sea levels on the NSW coast are projected to rise further, with the central estimate under the reference case (RCP4.5) being a 23cm additional rise by 2061 compared with 2020 levels.[73] Furthermore a significant portion of this is already locked in, with sea level rise projected to continue for centuries or even millennia, even under the lowest emissions scenarios.[74]

Sea level rise poses increased risk to NSW communities by exacerbating coastal erosion resulting in coastal recession (i.e. where beaches are eroded resulting in property damage and in loss of land), and inundation (where regular tidal or storm-surge related water levels rise,[75] inundating properties surrounding rivers, harbours, lagoons and other estuaries, as well as on the coast itself).[76]

Coastal erosion has attracted significant public interest in recent years, with notable events at Wamberal beach on the Central Coast, Main Beach in Byron Bay and at Narrabeen and Collaroy in Sydney. It can cause significant damage to properties and infrastructure, as well as loss of beach amenity. Some erosion events are associated with coastal storms, while on some coasts, cumulative

[69] Includes the value of insurance claims plus an additional 20 per cent for uninsured property loss. Further details in the technical appendix.
[70] Growth in sum of fiscal and private costs
[71] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
[72] CSIRO and Bureau of Meteorology, 13.
[73] Glamore et al., 'Sea Level Rise Science and Synthesis for NSW'.
[74] Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*.
[75] Note this section models storm surge damage arising from rising sea levels. This is different to the section on natural disasters which considers changes in the risk of storms forming themselves. The modelling approach is calibrated to preclude double counting.
[76] 'Coasts and Sea Level Rise'; Hague et al., 'Sea Level Rise Driving Increasingly Predictable Coastal Inundation in Sydney, Australia'.

erosion, or shoreline recession, can occur due to an imbalance in coastal sediment transportation systems. Rising sea levels are expected to contribute to additional erosion over coming decades.[77]

Sea level rise will also increase the number of properties that may become inundated at high tide levels. Sea levels are variable and impacted by "regular and irregular processes associated with astronomical bodies, ocean waves, oceanic currents, meteorological factors and geological phenomena."[78] An increase in average sea levels due to climate change will increase the number of properties exposed to inundation during high tides and increase the frequency of that inundation.

Economic and Fiscal Impact

Economic costs associated with sea level rise generally relate to damage to properties and infrastructure, as well as the loss of land through inundation and coastal recession. The NSW Government's framework on coastal management[79] gives local governments primary responsibility in managing the key risks associated with sea level rise, therefore for the purposes of the IGR's 'no policy change' assumption, fiscal costs would generally be assumed to be limited to damages and additional maintenance to existing infrastructure and potentially additional build costs for new infrastructure.

Both state and local governments, however, may consider the merits of a range of policy interventions if the projections outlined in this assessment are realised. Options include those aimed at protecting existing developments including sea walls, beach nourishment, house and infrastructure raising and tidal gauges on storm water, and those aimed at limiting unnecessary growth in exposure to sea level rise – generally regulatory interventions in the planning system. These all carry the potential for fiscal costs.

Projecting the costs of Sea Level Rise

The costs of sea level rise that have been modelled are limited to direct economic costs arising from the following two components:

a. structural damage to properties exposed to inundation or coastal erosion
b. land loss arising from inundation and coastal recession.

The number of addresses impacted by each type of risk is sourced from exposure assessments conducted by the (then) NSW Office of Environment and Heritage.[80] Additional adjustments were then made to the estimates to align with the forecast period and climate scenarios, with an overriding assumption that future development follows current development patterns. Damages are estimated as proportions of total structure and land value. Full details of the modelling approach are outlined in the technical appendix.

A limitation in this approach is its restriction to property damage. Sea level rise is also expected to be associated with a range of additional costs, including impacts on ecological services such as coastal wetlands and fisheries, and coastal infrastructure, for example ports and roadways. Modelling of the

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[77] Office of Environment and Heritage, 'Coastal Erosion in New South Wales Statewide Exposure Assessment Report'.
[78] Glamore et al., 'Sea Level Rise Science and Synthesis for NSW', 4.
[79] NSW Office of Environment and Heritage, 'Our Future on the Coast: An Overview of Coastal Management in NSW'.
[80] Office of Environment and Heritage, 'Coastal Erosion in New South Wales Statewide Exposure Assessment Report'; Hanslow et al., 'A Regional Scale Approach to Assessing Current and Potential Future Exposure to Tidal Inundation in Different Types of Estuaries'; Kinsela et al., 'Second-Pass Assessment of Potential Exposure to Shoreline Change in New South Wales, Australia, Using a Sediment Compartments Framework'.

potential costs of these additional areas is not available for this assessment but is an obvious candidate for any future extension of this work.

The key projections are outlined in Table 3. By 2061, between 35,000 and 40,000 properties are estimated to be exposed to inundation and a further 5,000 to 6,000 are estimated to be exposed to coastal erosion. Total direct annual economic costs are estimated at between $850 million and $1.3 billion per annum (in 2019-20 dollars), the bulk of which relates to the loss of land through inundation and coastal recession.

Sea level rise is also projected to continue well beyond 2061, with the rate of increase in the second half of the century being similar to that outlined in the table below under the reference case and lower warming scenarios, but nearly double under the higher warming scenario. Although the impact of this has not been modelled as part of this assessment, costs will generally increase with sea level rise and therefore are virtually certain to grow beyond 2061.[81]

Table 3 Projected Annual Sea Level Rise Costs by 2061 (real 2019-20 dollars):

	Damage to structures	Land Value Loss	Sea Level Rise (2020-61)[82]	Exposed Properties[83]
Lower Warming (RCP2.6)	$280m	$580m	20cm	39,000
Reference Case (RCP4.5)	$310m	$660m	23cm	41,000
Higher Warming (RCP8.5	$410m	$910m	30cm	46,000

Note that shocks are applied to the CGE model as proportions of factors of production. Dollar amounts reported here are preliminary and illustrative only. Sea Level Rise will result in costs additional to those listed in this table.

Heatwaves

Frequency, duration and intensity of heatwaves

The frequency, duration and intensity of heatwaves are all expected to increase over the next 40 years (see Chart 6). Since 1911 there has been a substantial increase in the frequency and duration of heatwaves across most of New South Wales, with some regions experiencing up to 18 additional heatwave days per year compared to the early 20th century.[84] As global temperatures increase, these trends are expected to continue, with the frequency and duration of heatwaves projected to increase, and their peak temperatures expected to be higher.

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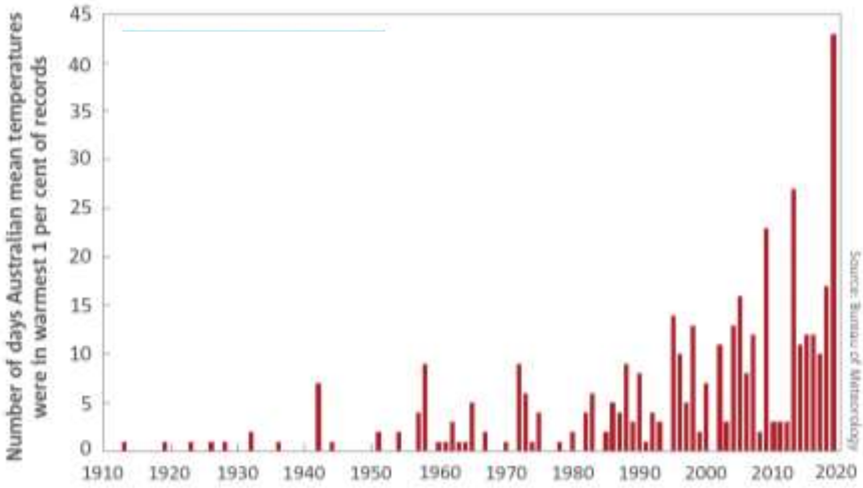
[81] Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*.
[82] Estimated additional sea level rise along the NSW coast by 2061 compared to 2020. Note global sea levels in 2020 have already increased by around 25cm since 1880.
[83] Note the number of exposed properties is not the same as the number of impacted properties in any given year.
[84] NSW Office of Environment and Heritage, 'Heatwaves Climate Change Impact Snapshot'.

Chart 6 Historical frequency of heatwaves in Australia



Source: Bureau of Meteorology State of the Climate 2020. Number of days each year where the Australian area-averaged daily mean temperature for each month is extreme. Extreme daily mean temperatures are the warmest 1 per cent of days for each month, calculcated for the period 1910 to 2019.

Economic and Fiscal Impact

Heatwaves can have a range of economic and fiscal impacts. Days of extreme heat can reduce workplace productivity, particularly for outdoor workplaces that require physical activity.[85] Heatwaves can also cause significant health issues and have been linked with more deaths than any other natural disaster in Australia. Beyond physiological impacts on humans, heatwaves can also inflict damage on infrastructure, for example by overheating electricity substations, and can disrupt service delivery.[86] All of these have the potential to impact the NSW fiscal position. Direct fiscal impacts include additional infrastructure costs through higher maintenance and repairs, building infrastructure to higher specifications, and costs relating to service delivery. Increased hospital admissions also add upward pressure to healthcare expenditure. Indirectly, economic impacts reduce the overall size of the economy, with flow on effects for government revenues.

Projecting the costs of heatwaves on workplace productivity

The economic impact of heatwaves is modelled in this assessment as lost productivity in selected industries arising from additional days of extreme heat. In line with the approach taken in the Garnaut Review, impacts are limited to four key industries where a significant proportion of work is conducted outdoors: agriculture, construction, manufacturing and mining. Also in line with the approach taken in the Garnaut Review, moderate productivity loss is assumed to occur where maximum daytime temperatures exceed 32°C, with higher productivity loss on days where maximum temperatures exceed 35°C. Temperature projections for each region of New South Wales are matched with ABS

[85] NSW Office of Environment and Heritage; Handmer, Ladds, and Magee, 'Updating the Costs of Disasters in Australia'; Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*; Deloitte Access Economics, 'Building Resilience in Our States and Territories'; Steffen, Hughes, and Perkins, *Heatwaves*; Bi et al., 'The Effects of Extreme Heat on Human Mortality and Morbidity in Australia'.
[86] National Climate Change Adaptation Research Facility (NCCARF), 'Impacts and Adaptation Response of Infrastructure and Communities to Heatwaves: The Southern Australian Experience of 2009'.

labour force data to determine the proportions of each industry that will be exposed to extreme heat. Full details of the modelling approach are in the technical appendix.

Projected workplace productivity loss from the four industries modelled is set out in Table 4. By 2061 additional working days lost to heatwaves is estimated at between 700,000 and 2.7 million per year, depending on the climate scenario. The highest impacts are on construction, mainly due to the high proportion of the workforce working outdoors. Agricultural productivity is also significantly affected across all climate scenarios, with more of this industry being in regions expected to experience a significant increase in days of extreme heat. For all industries, the impacts under the higher warming scenario are approximately double those of the reference case. A further increase in the number of days of extreme heat and increasing divergence across climate scenarios are projected beyond 2061.

Table 4 Working days lost per year due to heatwaves by 2061

	Agriculture	Construction	Manufacturing	Mining
Lower Warming (RCP2.6)	100,000	520,000	100,000	4,000
Reference Case (RCP4.5)	200,000	1,030,000	190,000	8,000
Higher Warming (RCP8.5)	380,000	1,940,000	360,000	15,000

Measured as the increase in days lost compared to current climatic conditions.

Note that a range of additional costs associated with heatwaves are not within the scope of this modelling. This includes impacts on human health and mortality[87] and on infrastructure construction and maintenance costs, as well as costs associated with infrastructure failure. Heatwaves also have potential to impact workplace productivity beyond those effects modelled for this analysis, including through impacts on additional industries and additional impacts from a reduction in cool nights, which can impact recovery and recuperation. These areas likely represent higher priority areas for future extensions of this research.

Agriculture

The other shocks included in this modelling have been related to specific climatic events. This fourth shock is instead focused on the aggregate impact of a range of climatic changes on a specific sector. This is separate and in addition to the workplace productivity shock of heatwaves relating to agriculture estimated in the previous section.

Crop output and quality

Crops are generally suited to a particular range of climatic conditions. Crop output and quality depend on factors including the range of temperature, timing and intensity of rainfall, water run-off, the concentration of carbon dioxide in the atmosphere, and soil properties including acidity, carbon and

[87] Bi et al., 'The Effects of Extreme Heat on Human Mortality and Morbidity in Australia'; Bambrick et al., 'The Impacts of Climate Change on Three Health Outcomes'; Coates et al., 'Exploring 167 Years of Vulnerability'; Longden, 'The Impact of Temperature on Mortality across Different Climate Zones'.

nutrient content, salinisation and erosion.[88] Climate change has the potential to impact all of these factors, with these impacts being highly location-specific.

In New South Wales, climate change is expected to reduce the availability of water in the Murray-Darling Basin region, impacting not only agricultural outputs but also posing challenges and risks to the livelihoods of communities in the region.[89]

Economic and Fiscal Impact

The agricultural sector, including forestry and fishing, accounted for 1.3 per cent of NSW Gross State Product in 2019-20. However, the industry is highly trade-exposed. It accounts for 10 per cent of total NSW exports, which can amplify its impact on the overall economy. Agricultural output is also the most volatile sector in the economy[90] and can be highly impacted by both chronic and acute climate change impacts including droughts and natural disasters. The impact of climate change on agricultural production could therefore impact both overall economic output as well as contribute to additional volatility.

Fiscal risks associated with the agricultural sector are generally concentrated in the role governments play to mitigate some of this volatility, including through the provision of drought and natural disaster relief assistance payments to primary producers. Additional risks lie in the provision of water infrastructure and management responsibilities under the Murray-Darling Basin Plan and water management legislation.

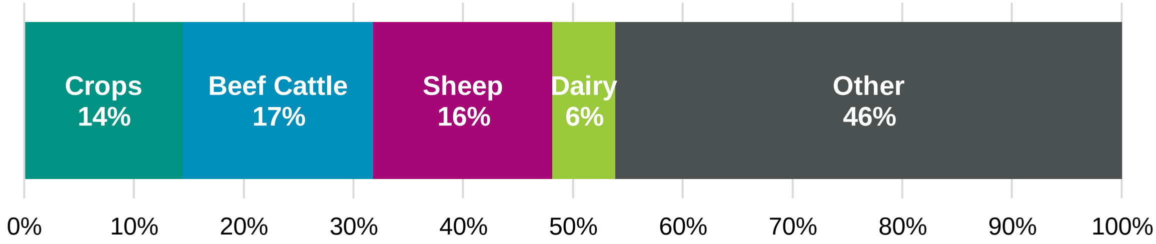
Projecting the costs of changed agricultural production

The impact of climate change on the agricultural sector is modelled as the expected change in agricultural output across five subsectors: crops, dairy cattle, beef cattle, sheep and other agriculture (which includes horticulture). The modelling was conducted by the CSIRO for NSW Treasury utilising their *Land Use Trade Offs* (LUTO) model,[91] which was used for the Australian National Outlook reports in 2015 and 2019.

The model can be used to estimate agricultural output given a range of factors including rainfall, temperature and productivity assumptions. These settings were calibrated to reflect the three climate scenarios. Further details of the modelling are set out in the technical appendix. As with other shocks included in this assessment, this is a partial assessment and does not account for a range of potential additional costs associated with the agricultural sector. In particular, the potential acute impacts of drought on the sector and regional economies more broadly have not been modelled but present a clear opportunity for further research.

[88] 'Projected Impacts of Climate Changes on Agriculture | NSW Department of Primary Industries'.
[89] Pearce et al., *Climate Change in Australia*.
[90] Measured as variance in annual agricultural output from ABS 5220.
[91]The LUTO model is described in detail in Bryan, B., Nolan, M., McKellar, L., Connor, J.D., Newth, D., Harwood, T., King, D., Navaroo, J., Cai, Y., Gao, L. Grundy, M., Graham, P., Ernst, A., Dunstall, S., Stock, F., Brinsmead, T., Harman, I., Grigg, N., Battaglia, M., Keating, B., Wonhas, A. and Hatfield-Dodds, S. 'Land-Use and Sustainability under Intersecting Global Change and Domestic Policy Scenarios'.

Chart 7 Makeup of NSW agricultural sector output 2019-20



Source: NSW Treasury calculations from LUTO and NSW Department of Primary Industries

The projections are set out in Table 5 below. Chart 7 provides some additional context for the size of each subsector in 2019-20. The reduction in crop production, a subsector that includes wheat and cotton, is projected to have the most significant economic impact, with this subsector constituting a significant proportion of overall agricultural output, and also experiencing climate impacts nearly twice those of other subsectors. Significant impacts are also expected in all other subsectors.

Table 5 Projected Changes in Agricultural Output Due to Climate Change 2061

Subsector	Lower Warming (RCP2.6)	Reference Case (RCP4.5)	Higher Warming (RCP8.5)
Crops	-6%	-9%	-11%
Beef Cattle	-3%	-5%	-6%
Sheep	-2%	-4%	-6%
Dairy	-3%	-5%	-6%
Other Agriculture	-0%	-1%	-1%

Translating this into dollar values, the annual value of lost production in agriculture is estimated at between $750 million and $1.5 billion (real 2019-20 dollars), depending on the climate scenario. Note that this estimate does not account for changes in the operation or structure of the economy or the agricultural sector – the overall economic impact of all shocks is more comprehensively measured using the CGE modelling.

Opportunities to extend this approach to climate risk assessment

As noted in the introduction, this research paper is aimed at setting out an approach to climate risk assessment and demonstrating this by assessing several key areas of risk. This approach could be extended in future research to incorporate a broader range of climate risks. Some of the higher priority areas for extending this approach are outlined below. This should not be considered an exhaustive list.

Water resources and drought

Climate change is expected to lead to a reduction in winter rainfalls across much of New South Wales, and an increase in summer rainfalls across parts of New South Wales, with many regions shifting from winter- to summer-dominated rainfall patterns. The aggregate impact is a shift toward drier overall conditions. These changes have already been observed: the BOM recently reported on key trends in Australia's climate including a 12 per cent decline in April-October rainfall in South

Eastern Australia since the late 1990s.[92] Streamflows across major catchments have also declined, including in the Murray-Darling Basin as well as the NSW South East Coast drainage division.[93] Higher temperatures associated with climate change, as well as the shift toward summer-dominated rainfall, are also likely to increase evaporation levels, leading to drier soil conditions, particular in the west of the State.[94]

While modelling of agricultural output incorporates changes in rainfall patterns, there are a range of additional economic and fiscal risks associated with changing rainfall patterns, including drought. These risks include the maintenance of the metropolitan and regional water supply; regulatory risks associated with the allocation of water, particularly west of the Great Dividing Range; the provision of financial assistance and other services to primary producers in the case of drought; and a range of second round economic effects. Consideration of these issues would likely benefit from climate data and rainfall modelling being conducted as part of the NSW Regional Water Strategies.[95]

Infrastructure

Climate change will introduce shocks and stresses to NSW's infrastructure system. This could affect infrastructure and lead to economic, social and environmental impacts. For example, the 2019-2020 bushfires alone damaged nearly $1 billion of Government infrastructure (equivalent to approximately 5% of the average NSW annual capital budget).[96] When infrastructure is damaged or impacted, it can affect the delivery of services to communities and have further social and economic impacts. When multiple shocks and stresses occur simultaneously or sequentially – as has been the case in 2020 – it can increase risks and compound the impacts.

The NSW Government is partnering with state government agencies, publicly owned infrastructure providers, local governments and XDI Pty Ltd to develop more comprehensive climate risk assessment tools for critical infrastructure and assets. Critical infrastructure classes being assessed include water supply, rail networks, electricity generation, transmission and distribution, telecommunications, hospitals, waste management facilities and coastal management infrastructure. These issues are also being considered through the implementation of the 2018 State Infrastructure Strategy, the NSW Government's Critical Infrastructure Resilience Strategy, and will be further explored as part of the 2022 State Infrastructure Strategy development.

Health and Mortality

While the total economic impacts outlined in the section on natural disasters include impacts on human health, this could be more systematically considered in future research, alongside other climate impact NSW health expenditures. Climate risks include increased instances of infectious diseases, the impact of heatwaves (noting this is likely partly offset by a decrease in cold-related health issues). This research could be further extended to cover mortality and incorporated into future population modelling.

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92 CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
93 CSIRO and Bureau of Meteorology.
94 NSW Office of Environment and Heritage, 'New South Wales Climate Impact Profile Technical Report: Potential Impacts of Climate Change on Biodiversity'.
95 NSW Department of Industry, 'New Climate Data and Modelling - Water in New South Wales'.
96 Source: INSW

Tourism

The potential for natural disasters to impact tourism is outlined in Box 1. In addition to this, some chronic climate risks impact particular tourist destinations: for example, the BOM has noted a declining trend in maximum snow depths in Australia's alpine regions since the 1950s,[97] which if continued is likely to impact New South Wales' ski fields. New South Wales could also be affected by the degradation of iconic tourist attractions such as the Great Barrier Reef reducing overall tourism to Australia. Nonetheless robust modelling is not available for inclusion in this analysis.

Other risks

Additional climate risks include:

- additional risks to agriculture, including dust storms and pests
- the warming and acidification of oceans
- impacts on biodiversity, including species decline
- impacts on supply chains and access to commodities
- international factors including trade, migration and geopolitical stability.

Most climate risk research also projects the intensification of risks as the three climate scenarios increasingly diverge through the second half of the 20th century and beyond.[98] For example, sea levels are projected to continue rising for centuries or even millennia: they could be up to 7 metres higher if the Greenland Ice Sheet melts, which is likely under the higher warming scenario and possible under all scenarios. The economic impact of this would, were it to occur, likely be orders of magnitude greater than that of anything modelled in this assessment. Future assessments may therefore consider extending the timeframe beyond the next forty years.

Finally, it is noted that even for those areas included within this assessment, there is scope to consider a wider range of costs. There is also scope to further refine the estimation method and projected outcomes for those costs that have been modelled.

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[97] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
[98] Intergovernmental Panel on Climate Change 2014, *Climate Change 2014: Synthesis Report*.

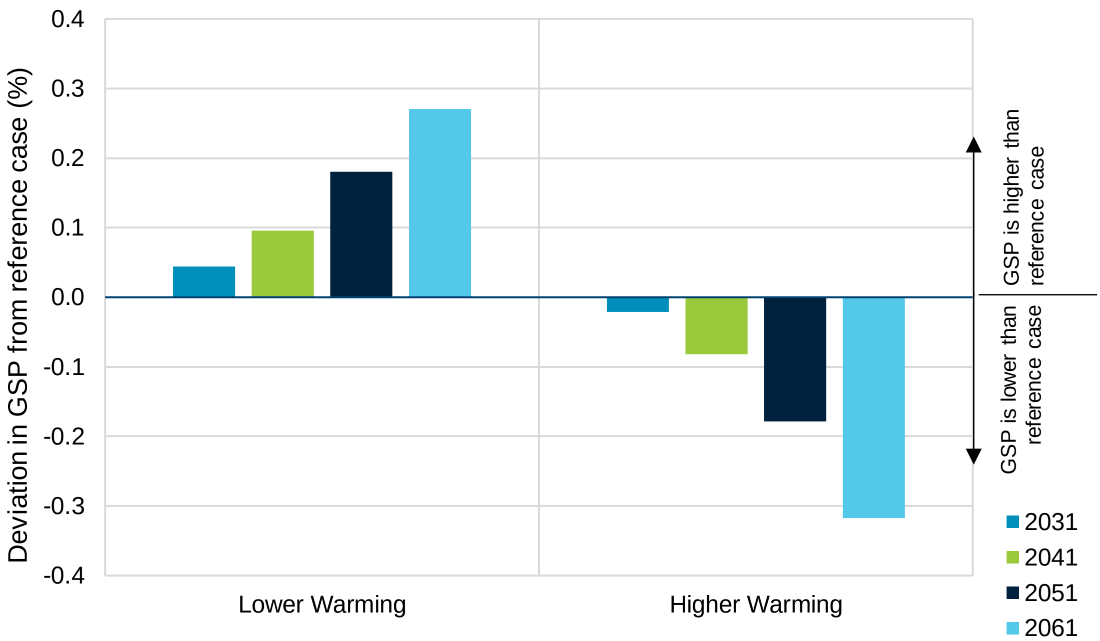
6. CGE Results

CGE Results

The findings of the CGE modelling are set out in Chart 8. As noted in section 3, the approach to CGE modelling focuses on assessing the sensitivity of long-term estimates to differences in the climate scenario, rather than the overall impact of climate change itself. For the four areas of risk included in the assessment, differences in the climate trajectory account for 0.6 per cent of GSP by 2061, measured as the difference between the higher warming scenario and the lower warming scenario.

In dollar terms, the projected benefit, in net present value terms, of realising the lower warming scenario compared to the higher warming scenario is estimated at $56 billion (real 2019-20 dollars) in additional income over the next forty years.[99]

Chart 8 Climate impacts on Gross State Product



Fiscal Impacts

Fiscal impacts arise from two sources: the direct impact of natural disaster expenditure, via the DRA, and the indirect impact of lower economic growth, which impacts a range of areas through the LTFPM, primarily revenue. For the four key risk areas included in the assessment, variance in the climate accounts for 0.05 per cent of the fiscal gap by 2061.

Note that the results presented here are preliminary and will be updated in line with overall economic forecasts and a range of other modelling for the IGR itself.

[99] Note this utilises a 2 per cent discount rate as was recently used by Deloitte. The Garnaut review utilised discount rates of 1.4 and 2.7 per cent. The Bank of International Settlements notes the choice of discount rate can radically impact modelling results and cites work by Nicholas Stern who argued the inherent arbitrariness in discount rate selection could lead to outcomes that are “grossly misleading”. For example using a 7 per cent discount rate the net present value of lost income is projected at $12 billion. Bolton et al., ‘The Green Swan’.

7. Discussion

The projections outlined in this paper are aimed at beginning a process for assessing the potential for the climate to impact the NSW economic and fiscal outlook. Section 5 presents projections of the impact of climate for four areas of risk across three different climate scenarios, while section 6 presents projections of how differences in the climate scenario would impact overall economic and fiscal outcomes.

Projections of individual climate effects (section 5) compared with projections of overall economic impact (section 6)

The projections in section 5 focus on the potential impact of climate change on specific sectors by projecting economic costs and other factors likely to be impacted. These are presented as ranges, depending on the climate scenario. The projections in section 6 indicate the difference in climate scenarios only, noting that NSW Treasury separately estimates long run economic growth through a top-down approach that incorporates productivity, population and participation. This approach is preferred because it allows the estimates of climate sensitivity to continue to be useful even where long run growth estimates change under the reference case.

Sectoral impacts

The projections outlined in section 5 indicate a range of costs are expected to increase significantly over the coming decades. Hazard risks of all three major natural disaster types impacting New South Wales are expected to increase, with bushfire risk projected to increase by 24 per cent under the higher warming scenario. Overall, the total annual economic cost of natural disasters is projected to increase to between $15.8 and $17.2 billion by 2061. Furthermore, volatility in the actual occurrence of natural disasters means annual economic costs could exceed $70 billion in some years. While fiscal costs under the DRA are significantly smaller and are shared with the Commonwealth under current policy settings, there is some risk associated with the combined impact of increased hazard risk and any changes in Commonwealth policy settings.

Sea level rise is projected to impact coastal communities and annual costs have potential to exceed $1 billion per year by 2061. As with natural disasters these costs will not be evenly distributed, with much higher costs likely in some years. This could lead to pressure on state and local government to review policy settings, both in terms of mitigating the risk to existing properties and reducing development in exposed areas.

Heatwaves are projected to lower workplace productivity across a range of regions. Combined with projected climatic impacts on agriculture and issues relating to water security (not modelled in this paper), effects are likely to be felt most acutely in inland regional areas of the State.

Contextualising in the projection method

The results in section 6 should not be interpreted as the overall costs of climate change. As outlined in the previous paragraph, they represent the sensitivity of economic outcomes under different climate scenarios. Given the timescales in which the effects of climate change operate, differences between the three climate scenarios are relatively minor until the second half of this century, meaning that so too are projected changes in output and the fiscal gap across these scenarios. Extending the projection beyond the IGR's 2061 projection timeframe would certainly yield more significant differences across the three climate scenarios.

This assessment has also been limited to four areas of climate risk, with the intention of demonstrating the viability of the approach to climate risk assessment. Extending the range of climate risks beyond these would also certainly increase the projected impact of differences across climate scenarios, even within the limited projection timeframe. An additional limitation is that this modelling has considered only a subset of costs relating to each of these risks. For example, natural disasters are expected to impact the costs of constructing and maintaining infrastructure, but these costs have not been incorporated into the economic or fiscal modelling. Similarly, costs arising from heatwaves, including infrastructure and healthcare are not included.

Comparisons with other estimates

Previous research of a more comprehensive set of risks have estimated that unmitigated climate change (RCP8.5) would impact the NSW economy by between around one and two per cent by 2050, with costs then rising sharply over the second half of the century.[100] These studies measured the costs of climate change against a hypothetical 'no climate change' scenario, whereas this paper has estimated variance based on three climate scenarios. Given this difference in modelling approach, the more limited range of risks assessed and the relatively short projection period to 2061, these findings appear broadly in line with this other research.

Smoothing

Long term economic and fiscal modelling is not intended to predict exactly how each year will unfold, but rather the general direction and scale of overall trends. Inevitably long-term projections, including this one, are represented as smooth lines. In reality, this is not how climate risks are expected to play out in New South Wales. The actual occurrence of natural disasters, heatwaves and storm surges is highly variable. If the variability in natural disaster costs experienced over the past decade were the same in the years to 2061, the actual total economic cost of natural disasters in any one year could be as low as $30 million and as high as $75 billion. Similarly, climatic factors which impact agricultural production may be benign for many years before abruptly becoming extremely damaging. Climate and economic modelling cannot predict in advance when or where these events will occur and hence must rely on smoothed projections. This is an unavoidable limitation.

Future Extensions

The primary purpose of this assessment has been to pilot an approach for climate risk assessment and to demonstrate that approach with regards to a relatively limited range of risks. The intention has been to first demonstrate the viability of the framework by focusing on only those areas for which costs and climate risks could be estimated relatively robustly. It is anticipated that this approach can be developed and extended as the NSW Government moves toward more systematically accounting for climate risks across Government.

Two priority candidates for further extension of this approach have been identified: water security and infrastructure. These both have potential to have much more significant impacts on the fiscal position over the coming decades. Furthermore, modelling the overall economic impact of these climate risks could better assist the Government as it develops regional water strategies, and longer-term infrastructure priorities. A further extension would be beyond the forty-year timescale used for this

[100] Garnaut, *The Garnaut Climate Change Review*; Deloitte Access Economics, 'A New Choice'.

assessment. The findings are focused primarily on differences between climate scenarios, and these differences are expected to grow significantly over the second half of the century and beyond.

8. Conclusion

This paper has piloted an approach to assessing fiscal and economic risks associated with climate change and demonstrated this through an initial assessment of four key climate impacts. A range of impacts are found for each of the four areas of risk, with the largest being in the total economic costs of natural disasters which is projected to increase to between $15.8 and $17.2 billion per year by 2061 (real 2019-20 dollars). The sensitivity of the economic and fiscal outlook with regards to these risks under different climate scenarios accounts for 0.6 per cent variation in Gross State Product and 0.05 per cent of the fiscal gap by 2061.

These estimates do not constitute a comprehensive assessment of the impacts of climate change but are intended to focus on a more limited set climate impacts relating to four key areas of risk. Future research could extend this assessment to account for additional risks. Higher priority areas for research include water security including drought and costs associated with the construction and maintenance of infrastructure. Extensions to the projection period beyond 2061 will also likely yield further useful information.

Despite the relatively limited scope of this study, the methodology has nonetheless provided for a discrete assessment of four areas of climate risk and providing an indication of the sensitivity of New South Wales' economic and fiscal outlook under different scenarios in relation to these risks. This is the first time a quantitative assessment of climate risks has been conducted for any Australian jurisdiction as part of their long-term fiscal planning processes. The inclusion of this analysis for the 2021 IGR should provide confidence that New South Wales is managing risks in a robust and transparent manner.

TECHNICAL APPENDIX

Victoria University Regional Model

The Victoria University Regional Model (VURM), an evolution of the Monash Multi-Region Forecasting Model (MMRF) used for the Garnaut Review, is used to produce a number of scenarios for the NSW and Rest of Australia (RoA) economies. The first is a reference case calibrated to match the IGR's central assumptions derived in separate research regarding population growth, participation and productivity growth. In addition, it incorporates the intermediate climate scenario (RCP4.5). The remaining scenarios depart from the reference case in response to different assumptions relating to the costs of natural disasters, sea level rise, heatwaves and agricultural production. This section briefly describes the VURM model and then explains some of the key behavioural assumptions underlying the deviation scenarios.

Model settings and calibration

In the version of VURM used for the study, there are 83 industry sectors in two regions, NSW and the RoA. The latter region is an aggregation of the other five Australian states and the two territories.

Investment is allocated across industries to maximise rates of returns to investors (households, firms). Capital creators assemble, in a cost-minimizing manner, units of industry-specific capital for each industry. Each state has a single representative household and a state government. There is also a federal government. Finally, there are foreigners, whose behaviour is summarised by export demand curves for the products of each state and by supply curves for international imports to each state.

As is standard in CGE models, VURM determines the supply and demand for each regionally produced commodity as the outcome of optimising behaviour of economic agents. Regional industries choose labour, capital and land to maximize their profits while operating in a competitive market. In each region a representative household purchases a particular bundle of goods in accordance with the household's preferences, relative prices and its amount of disposable income.

Interregional trade, interregional migration and capital movements link each regional economy. Governments operate within a fiscal federal framework.

VURM provides results for economic variables on a year-on-year basis. The results for a particular year are used to update the database for the commencement of the next year. In particular, the model contains a series of equations that connect capital stocks to past-year capital stocks and net investment. Similarly, debt is linked to past and present borrowing/saving and regional population is related to natural growth and international and interstate migration. For a detailed description of the theoretical structure of the VURM model, see Adams et al (2011).[101]

[101] Adams et al., 'MMRF: Monash Multi-Regional Forecasting Model: A Dynamic Multi-Regional Model of the Australian Economy'.

Key assumptions underlying the alternative scenarios

Labour markets

At the national level, it is assumed that (lagged) real wages adjust in response to shocks imposed on the model. These changes can cause employment to deviate from its reference value initially, but thereafter, real wage adjustment steadily eliminates the short-run employment consequences. This labour-market assumption reflects the idea that in the end national employment is determined by demographic factors, which are unaffected by climate change.

At the regional level, labour is assumed to be mobile between state economies. Labour is assumed to move between regions to maintain inter-state unemployment rate differentials at their reference-case levels. Accordingly, regions that are relatively favourably affected by the different climate costs will experience increases in their labour forces as well as in employment, at the expense of regions that are relatively less favourably affected.

Private consumption and investment

Private consumption expenditure is determined via a consumption function that links nominal consumption to household disposable income (HDI). In the alternative simulations, the average propensity to consume (APC) is an endogenous variable that moves to ensure that the balance on current account in the balance of payments remains at its reference case level. Thus, any change in aggregate investment brought about by different climate costs is accommodated by a change in domestic saving, leaving Australia’s call on foreign savings unchanged.

Investment in all but a few industries is allowed to deviate from its reference-case value in line with deviations in expected rates of return on the industries’ capital stocks. In the alternative scenarios, VURM allows for short-run divergences in rates of return from their reference-case levels. These cause divergences in investment and hence capital stocks that gradually erode the initial divergences in rates of return.

Government consumption and fiscal balances

VURM contains no theory to explain changes in real public consumption, with fiscal impacts modelled separately in Treasury’s LTFPM. In the CGE simulations, public consumption is simply indexed to nominal GDP. The fiscal balances of each jurisdiction (federal, state and territory) as a share of nominal GDP are allowed to vary relative to reference case values in line with projected changes in expenditure and income items.

Production technologies and household tastes

VURM contains many variables to allow for shifts in technology and household preferences. In the alternative scenarios, most of these variables are exogenous and have the same values as in the reference-case projection. The exceptions are technology variables that are used to introduce the shocks to the model.

Shock Estimation

Natural Disasters

Data

Insurance Council of Australia Catastrophe Database

The first of two key data sources utilised in the modelling is insurance claims data, available from the Insurance Council of Australia's Catastrophe Database.[102] This database includes all major catastrophes (defined as claims exceeding $10 million) since 1967.[103] The data was filtered to exclude natural disasters not relating to New South Wales. Where events impacted multiple states, the NSW proportion was estimated using descriptive information provided in the database (for example some descriptions included a breakdown of the number of claims or impacted properties by state). Events were classified as either floods, storms (including hail and thunderstorms, east coast lows, tropical cyclones or other severe weather), bushfires and other (primarily earthquakes).[104] Events described as both storms and floods were classified as floods where this appeared to be the primary driver of damages.

Costs in the catastrophe database are stated in both original and 'normalised' terms, with the latter utilised to derive current expected costs. The ICA database only includes records of insured losses, therefore excluding uninsured losses. The Productivity Commission notes that estimates of the proportion of losses that are uninsured vary considerably across sources, but cites the Actuaries Institute estimates that uninsured losses account for 20 to 40 per cent of direct economic losses,[105] hence the mid-point of this estimate (i.e. 30 per cent) is adopted as the assumption throughout this modelling.

Disaster Recovery Funding Arrangements (DRA)

Disaster relief and recovery costs are based on NSW Government annual returns to the Commonwealth under the *Disaster Recovery Funding Arrangements (DRA).*[106] Partial records are available since 2002-03, via the Commonwealth Productivity Commission, with more detailed records available between 2009-10 up to an including 2019-20. For the purposes of deriving current expected costs, expenditure from previous years is adjusted using normalisation factors derived from the insurance council database.

The DRA records present an additional challenge due to the relatively limited time series and extreme volatility in natural disaster expenditure. Estimates of 'average' annual normalised expenditure are heavily influenced by single events, specifically the 2019-20 bushfire season. The records also do not cover enough time for earthquakes to feature. To account for this, the DRA records are adjusted with

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[102] Insurance Council of Australia, 'Catastrophe Data'.
[103] However some inconsistencies between the current online database and previous versions were noticed. For example the updated database did not include the 1994 NSW bushfires, which resulted in $59 million in claims, as well as several other major events. Records were therefore adjusted to account for obvious omissions that were found to be present in previous versions of the database, accessed via earlier versions of Insurance Council of Australia Catastrophe Database accessed via web.archive.org.
[104] Other also includes a building explosion and an event in 1990 that is not described with sufficient detail to allocate a category.
[105] Institute of Actuaries of Australia, 'Actuaries Institute Submission to Royal Commission into National Natural Disaster Arrangements'.
[106] Formerly the Natural Disaster Relief and Recovery Arrangements (NDRRA), which this paper refers to interchangeably with the DRA.

reference to the longer insurance claims time series. This has the effect of 'diluting' the 2019-20 bushfires from the baseline to ensure this single event does not unduly impact the baseline estimates. Expected DRA expenditures relating to earthquakes (and other events) are assumed to be proportionate to the overall ratio of DRA expenditure to insurance losses.

Natural disaster expenditures are partially reimbursed by the Commonwealth, with arrangements generally providing for higher proportional reimbursement in years with higher expenditure levels. Over the period 2008-09 to 2019-20, 39 per cent of costs were reimbursed to New South Wales, which is adopted as the long-run assumed average for the modelling.[107]

Estimating total economic costs

There is no consistent approach to the collection of costs relating to natural disasters in NSW or Australia. As a result, costs additional to those captured by insurance records and NSW Government DRA returns must be estimated using standardised ratios. These assume that, at an aggregate level, unmeasured costs, including direct, indirect and intangible costs, are proportionate to measured insurance losses. These ratios were sourced from Deloitte's report *Building Resilience to Natural Disasters in our States and Territories*,[108] which itself draws on a Bureau of Transport Economics Report from 2001,[109] as well as some more recent case studies. The ratios used to estimate total economic costs are set out in Table 6. Estimates of total economic costs are illustrative only and not included in the CGE or fiscal modelling.

Table 6 Ratio of total economic costs to recorded insurance losses

Disaster Type	Ratio
Bushfires	4.9
Floods	21.7
Storms	4.9

Source: Deloitte Access Economics[110]

Projecting underlying costs growth

Future expected natural disaster costs are derived by first estimating that portion of growth relating to growth in the population and economy. This is based on the same principle as is used to 'normalise' historic natural disaster costs. However, using this exact same method to project would require projections of the future replacement value of the housing stock, which are unavailable, hence a proxy measure is required. The Productivity Commission noted that growth in the value of insurance losses was consistent with trend growth in GDP, which accounts for population, wealth and prices. Given this, and the fact that projections of GSP are readily available as part of the calibration of the reference case, growth in GSP is used as a proxy for underlying growth in expected annual natural disaster costs. Note this estimate is somewhat lower than that used in Deloitte's 2017 report *Building Resilience to Disasters in our States and Territories*, which, like normalisation practices, is based on

[107] Note that this modelling is undertaken on the basis of no policy change, therefore any proposals to change the funding arrangements are not considered in this analysis. 39 per cent refers to the 'normalised' average reimbursement.
[108] Deloitte Access Economics, 'Building Resilience in Our States and Territories'.
[109] Bureau of Infrastructure, Transport and Regional Economics, 'Economic Costs of Natural Disasters in Australia'.
[110] Deloitte Access Economics, 'Building Resilience in Our States and Territories'.

the projected value of the housing stock, but unlike normalisation methods, also includes the value of land.

Changes in hazard risk under climate change

The next section sets out the approach to estimating changes in hazard risks for the three key natural disaster types included in the modelling: bushfires, flooding and storms. The risk of other natural disasters (which mainly refers to earthquakes) are assumed not to be impacted by climate change.

Bushfires

The frequency and intensity of bushfires is impacted by a range of factors. These include climate, which can influence rainfall, impacting fuel load and dryness, and weather including that measured by the McArthur Forest Fire Danger Index (FFDI) as well as sources of ignition such as lightning. Fire prevention and management practices also impact the intensity and destructiveness of fires and best practice in fire management and response is constantly evolving.[111] The occurrence and intensity of fires, as well as their cost, are determined by complex interactions between all of these factors. Modelling the evolution of these factors and their interactions over the coming decades is extremely challenging, however it is relatively clear that climate change has already led to an increase in dangerous fire weather. These trends are predicted to continue into the future, with the extent of further changes linked to the trajectory of GHG emissions.[112]

Modelling conducted by XDI Pty Ltd,[113] and provided to Treasury, provides an indication of how climate change could impact bushfires risks across New South Wales under the higher warming (RCP 8.5) scenario. The modelling utilises a modified version of the Hot-Dry-Windy (HDW) index as the measure of fire risk. HDW is more commonly used in the United States as an alternative to FFDI. It is normally calculated using hourly readings at multiple atmospheric layers, however for this modelling it has been estimated using projected daily surface temperature data. This means it does not explicitly account for changes in the upper atmosphere which were associated with the development of firestorm events such as those observed during the 2019-20 bushfire season.

A historical series was first estimated using data sourced from the Bureau of Meteorology. Forward projections utilise a General Circulation Model (GCM) from the Max Planck Institute (MPI) provided through CORDEX. Regional climate modelling is sourced by the Climate Limited-area Modelling Community (CLMcom). This was combined with fire exposure maps developed by XDI Pty Ltd which utilised satellite imagery of forest canopy cover, spatial mapping of urbanisation and additional adjustments to provide an indication of the exposure of specific properties. The modelling also incorporated historical annual burn extents from sources including insurance records, the CSIRO (Bushfires in Australia: Prepared for the 2009 Senate Inquiry into Bushfires in Australia July 2009) and satellite data. The overall results were then calibrated to the historical records of building losses available in insurance data.

There are some limitations to this modelling: it does not account for grass fires or account for coincident bushfire risk factors such as the combined impact of both high fire danger weather, sustained drought or fuel load. Given expected trends in these other factors, this suggests these results are likely a conservative estimate. A further limitation is that the modelling is based on the

[111] CSIRO, 'The 2019-20 Bushfires'.
[112] CSIRO; Clarke, 'Climate Change Impacts on Bushfire Risk in NSW'.
[113] Mallon et al., 'Climate Change Risk to Australia's Built Environment: A Second Pass National Assessment'.

higher warming scenario (RCP8.5), with estimates for RCP4.5 and RCP2.6 derived by assuming these would be proportionate to the total expected change in global mean surface temperatures under each scenario.

While again emphasising that it is not possible to quantify the complex interactions of all factors impacting bushfire risks, the modelling nonetheless provides an indication of how climate change is likely to impact those factors which have been modelled. The modelling indicates that by 2061, these factors are expected to increase the risk of bushfires by 24 per cent under RCP8.5, 17 per cent under RCP4.5 and 2 per cent under RCP2.6. Although these results are indicative only, and do not capture the full range of factors impacting bushfire risks, they are nonetheless utilised in this assessment to provide an indication of changed bushfire risks under climate change. The only alternative approach would be to assume no change in bushfire risk, and thus ignore known changes to these key risk factors.

Table 7 Expected Annual Bushfire Costs in 2061 (real 2019-20 dollars)

		Total Economic Costs	Direct Economic Costs[114]	Direct Fiscal Costs under the DRA	Annual Growth in Nominal Fiscal Costs[115]
2020-21		$270m	$80m	$50m	
2060-61	**Lower Warming (RCP2.6)**	$830m	$240m	$140m	5.3%
	Reference Case (RCP4.5)	$950m	$280m	$160m	5.7%
	Higher Warming (RCP8.5)	$1,010m	$300m	$170m	5.9%

Source: NSW Treasury

Flooding

Damages associated with floods are influenced by a range of complex factors. These include the frequency and intensity of extreme precipitation events, the location and characteristics of properties and infrastructure, draining capacity of waterways and dam storage.

Climate change is expected to increase the frequency and intensity of extreme precipitation events, even for areas which are expected to see a reduction in average annual rainfall. A warmer atmosphere is able to hold more water vapour, with the carrying capacity increasing by around 7 per cent for every degree of global warming. Higher moisture content, as well as warmer ocean temperatures, in turn can provide more energy for atmospheric processes that generate extreme rainfall, further increasing the likelihood of these events.[116] Short term extreme precipitation events

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[114] Includes the value of insurance claims plus an additional 20 per cent for uninsured property loss. Further details in the technical appendix.
[115] Growth in sum of fiscal and private costs
[116] Pearce et al., *Climate Change in Australia*; CSIRO, 'Understanding the Causes and Impacts of Flooding'; CSIRO, 'FAQs on Floods'; Bruyere et al., 'Severe Weather in a Changing Climate (2nd Edition)'.

have been observed to increase at a higher rate than the moisture-carrying capacity of the atmosphere.[117]

These changes have already been observed, with some regions in Australia recording a 10 per cent increase in the intensity of short-duration extreme rainfall events.[118] For New South Wales specifically, NARCliM projections indicate that rainfall extremes are projected to increase in the near and far future. These changes are within the range of inter-annual variability across all regions in the period 2020-39, however some indices and regions show statistically significant increases for the period 2060-79.[119]

Modelling changes in natural disaster costs relating to floods in this paper relies on two separate sources. Modelling provided to Treasury by XDI Pty Ltd, based on a national risk assessment, indicates that the property value at risk from floods will increase by 12 per cent by 2060 under RCP8.5. This was checked against separate modelling provided to Treasury by Munich Re, which indicates potential damages from a 100-year ARI flood will increase by between 9 and 27 per cent by 2050, also under RCP8.5.[120]

Modelling was not available for the other climate scenarios, which were instead estimated as fixed proportions of the highest warming scenario. The IAG report *Extreme Weather in a Changing Climate*, notes that the relative change in maximum one day rainfall in Eastern Australia by 2080-99 under RCP4.5 is around half that expected under RCP8.5, and that changes are less evident under RCP2.6.[121] On this basis, and noting the limitation that maximum one day rainfall is only one of many factors that should ideally be considered, flood risk under RCP4.5 is estimated to increase by half the amount of RCP8.5. Risk under RCP2.6 is estimated to remain similar to current levels.

As with changes in bushfire risk, these estimates should be treated with caution and it is acknowledged they capture expected changes in only some of the many complex factors impacting overall changes in flood risk.

Table 8 Expected Annual Flood Costs in 2061 (real 2019-20 dollars)

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[117] Bruyere et al., 'Severe Weather in a Changing Climate (2nd Edition)'.
[118] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
[119] Evans et al., 'NARCliM Extreme Precipitation Indices Report.'
[120] The range relates to uncertainty regarding floor height, with the lower estimate corresponding with a 50cm floor height assumption for all properties, and the higher estimate corresponding with 0cm floor height. Insurers generally resolve this uncertainty in ex post assessments.
[121] Bruyere et al., 'Severe Weather in a Changing Climate (2nd Edition)', 442.

		Total Economic Costs	Direct Economic Costs[122]	Direct Fiscal Costs under the DRA	Annual Growth in Nominal Fiscal Costs[123]
2020-21		$2.5b	$170m	$90m	
2060-61	Lower Warming (RCP2.6)	$7.8b	$510m	$270m	5.3%
	Reference Case (RCP4.5)	$8.2b	$540m	$290m	5.4%
	Higher Warming (RCP8.5)	$8.7b	$570m	$300m	5.6%

Source: NSW Treasury

Storms

A range of severe weather events are present in the natural disaster records, with subtle differences in classifications between DRA and insurance records. For the purposes of this analysis, storms are taken to include hail and thunderstorms, east coast lows, tropical cyclones, and other severe weather excluding events where flooding was the primary driver of damages. Hailstorms accounted for 69 per cent of insurance losses relating to storms, with East Coast lows accounting for a further 12 per cent and cyclones just 2 per cent.[124]

Hailstorms and Thunderstorms

Projections of severe thunderstorms, including those that produce hail, are challenging for climate models, which generally are not calibrated at a small enough scale to simulate the development of thunderstorms, or able to effectively simulate the processes required for hail development.[125] Challenges also exist in interpreting the observational record, which are strongly influenced by the population density of locations impacted by hail, leading to low confidence.

However, a range of evidence suggests climate change could increase the instance of severe thunderstorms, including those with hail. Radar observations across the NSW coast indicate an increase in the number of 'hail days' over the past 20 years, although the occurrence of hailstorms is also known to vary with the El Nino Southern Oscillation, meaning additional caution needs to be applied to observed trends over relatively short periods. Warming is likely to increase "convective available potential energy," which would increase the risk of severe thunderstorms developing,[126] but other factors are also necessary for hailstorm development, and more research is required to definitely determine their likely future trend.

[122] Includes the value of insurance claims plus an additional 20 per cent for uninsured property loss. Further details in the technical appendix.
[123] Growth in sum of fiscal and private costs
[124] Note this excludes the impact of ex-tropical cyclones which have generally caused extensive flood damage.
[125] Bruyere et al., 'Severe Weather in a Changing Climate (2nd Edition)'; NSW Office of Environment and Heritage, *Impacts of Climate Change on Natural Hazards Profiles.*
[126] Allen, Karoly, and Walsh, 'Future Australian Severe Thunderstorm Environments. Part II'.

East Coast Lows

East Coast Lows (ECLs) are intense low-pressure systems that occur off the east coast of Australia, with an average of 10 events occurring every year. A decline in the overall number of winter ECLs has been observed in recent years, but the number of more intense ECLs has increased. Modelling by the *Eastern Seaboard Climate Change Initiative*,[127] a research collaboration led by the NSW Government, projects that that this trend will continue into the future. Specifically, the number of less severe ECLs, and the number of ECLs overall, is expected to decline. However, there is projected to be a 28 per cent increase in the number of *severe* ECLs[128] in summer, alongside a 6 per cent decline in severe winter ECLs by 2050.

Tropical Cyclones

Climate change is expected to reduce the frequency of tropical cyclones forming near Australia but increase the intensity of those that do.[129] Tropical cyclones are projected to track further south, which presents a potentially serious threat to the north eastern corner of New South Wales.[130] Modelling by Munich Re indicates the potential scale of an intense tropical cyclone event impacting New South Wales. Under current conditions, the total NSW exposure to a 100-year ARI tropical cyclone producing winds over 143kmh in New South Wales is estimated at $20.8 billion, more than doubling to $51.8 billion under the mid-range climate scenario (RCP4.5) by 2050.[131] Under the higher warming RCP8.5 scenario, the projected impact is 25 per cent higher still. For the purposes of this modelling, risks are assumed to increase linearly in each year between 2020 and 2050, and that trend is further extended until 2061. Risks under the lower warming scenario are assumed to lie between current conditions and the reference case. The change in tropical cyclone risk by 2061 is therefore estimated at 102 per cent under the lower warming scenario, 205 per cent under the reference case and 291 per cent under the higher warming scenario.

In addition to the usual caveats regarding the need to treat the estimate of changed risk with significant caution – tropical cyclones are driven by a complex array of factors, and modelling can only capture some of these – additional caution is required for the modelling of costs associated with tropical cyclones. Only one full strength tropical cyclone has made landfall in NSW since 1967 – cyclone Nancy, which crossed the coast near Byron Bay in 1990. Hence projected costs are made off a very small base. However, there is some evidence that NSW has been experiencing a historically unusual absence of cyclones in recent decades, thought to relate to an increase in El Nino activity. Hence this baseline may prove to be too conservative. Furthermore, housing and other buildings in New South Wales have generally not been built to withstand cyclonic conditions, exacerbating the potential for damages.[132] There is therefore considerable uncertainty regarding the increased risk of cyclones estimated for this modelling.

Expected costs of storms

While it is clear that climate change will impact the timing, frequency and intensity of hail and thunderstorms, and east coast lows impacting New South Wales, the evidence is somewhat

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[127] The Eastern Seaboard Climate Change Initiative is a research collaboration led by the NSW Government and includes the Bureau of Meteorology, the Sydney Institute of Marine Science, UNSW, the University of Newcastle, and Macquarie University. More details are available at 'Eastern Seaboard Climate Change Initiative'.
[128] Defined as wind speed above 20ms
[129] CSIRO and Bureau of Meteorology, 'State of The Climate 2020'.
[130] Abbs, 'The Impact of Climate Change on the Climatology of Tropical Cyclones in the Australian Region', 8–9.
[131] Note this modelling is based on the current number and value of housing stock. The estimate would be significantly higher if applied to projected housing stock values and numbers in 2050.
[132] Thompson, 'Severe Cyclones Are Spreading Further South and It Could Mean Tens of Billions in Damages'.

ambiguous regarding the sign and quantum of changes in the risk profile. This assessment therefore assumes no change in the current risk profile relating to these storms under any of the climate scenarios. A range of research is also expected to report in the near future which may provide additional detail in quantifying future hazard risk from storms.[133] The change in storm risk is therefore derived entirely from changes in tropical cyclone risk, which while quite high, have only accounted for a relatively small share of total storm-related natural disaster losses.

Table 9 Expected Annual Storm Costs in 2061 (real 2019-20 dollars)

		Total Economic Costs	Direct Economic Costs[134]	Direct Fiscal Costs under the DRA	Annual Growth in Nominal Fiscal Costs[135]
2020-21		$1.8b	$514m	$44m	
2060-61	**Lower Warming (RCP2.6)**	$5.5b	$1,600m	$137m	5.3%
	Reference Case (RCP4.5)	$5.6b	$1,627m	$139m	5.4%
	Higher Warming (RCP8.5)	$5.7b	$1,650m	$141m	5.4%

Sea Level Rise

Data

Data on the number of addresses exposed to risks associated with sea level rise is sourced from two studies produced by the NSW Office of Environment and Heritage (OEH), now part of the NSW Department of Planning, Industry and Environment:

- Coastal Erosion in New South Wales: Statewide Exposure Assessment (2017)
- NSW Estuary Tidal Inundation Exposure Assessment (2018).

Both of these assessments project the number of NSW addresses exposed to coastal erosion, or inundation due to sea level rise, as well as the proportions of these properties expected to be exposed. Specifically, the coastal erosion assessment includes projections of the number of NSW addresses exposed to coastal erosion during a 100-year ARI storm surge in 2050 under a higher warming scenario. The tidal inundation assessment includes projections for three increased sea levels (0.5m, 1.0m, 1.5m) and delineates between properties projected to lie within the High High Water Solstice Springs (HHWSS) tidal plan, which is reached regularly throughout the year, and those projected to be vulnerable to exposure during 100 year ARI storm surges. It also improves on earlier "bathtub" methods by accounting for variation in tidal levels both between and along estuaries.

[133] Bruyere et al., 'Severe Weather in a Changing Climate (2nd Edition)', 96.
[134] Includes the value of insurance claims plus an additional 20 per cent for uninsured property loss. Further details in the technical appendix.
[135] Growth in sum of fiscal and private costs

Data on land values is obtained from the NSW Valuer General's 2019 report on NSW Land Values, and the value of structures is obtained from the ABS (5220 Table 21). Sea level rise projections are based on 50 per cent exceedance values of NSW coastal sea level rise, using projections for each RCP in the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate,[136] calculated by taking an average of cells located along the NSW coast. Using the 50 per cent exceedance value implies that there is a 50 per cent chance actual sea level rise will exceed these values.

Projection Method

An estimated of the number of properties *exposed* to each hazard in each year of each projection was obtained by first assuming the overall size and value of the housing stock would increase in line with existing development patterns. This relies on the (informed) assumption that development controls are not currently deterring further development in exposed areas. It was further assumed that the number of exposed properties in any single year would be proportionate to the estimated sea level rise in that year and scenario compared with the levels assessed in the two studies. While this oversimplifies the relationship between sea level rise and the number of exposed properties, which is likely non-linear due to the presence of development controls and natural topological features, it is a necessary simplification given the available data and should provide a reasonable approximation.

For regular inundation (i.e. the HHWSS tidal plane), the number of *impacted* properties in any given year was assumed to be the *change* in the number of properties exposed in that year. This is on the grounds that properties can only be damaged once, and also excludes properties already exposed to inundation, which are assumed to have already been impacted. The number of properties impacted by inundation during 100-year ARI storm surges is assumed to be one per cent of total exposed properties less those already counted as exposed to regular inundation. The number impacted by coastal erosion is just one per cent of total exposed properties.

Damages from coastal erosion and regular inundation were assumed to include structural damage to properties as well as loss in land value, with both of these increasing as more of the properties were inundated. Damages from 'storm surge' inundation were assumed to be limited to structural damage only and estimated in line with standard flood damage assumptions used by insurers.[137] The value of structures was assumed to be in line with the statewide average, while land values were assumed to be higher given impacted properties were in coastal and waterfront locations. Specific values were drawn from previous economic assessments of coastal erosion.[138]

Summary results are presented in the main body, while

Table 10 provides a breakdown of damages by each hazard type. Note that shocks are applied to the CGE model as proportions rather than dollar values, and modelling of the housing market is not yet complete for the 2021 IGR. Hence the below table is indicative and based on projections of housing and land values from the 2016 IGR.

Table 10 Expected annual damages from sea level rise in 2061 (real 2019-20 dollars)

	Coastal Erosion	Regular Inundation	Storm Surge Inundation

[136] Intergovernmental Panel on Climate Change, 'Special Report on the Ocean and Cryosphere in a Changing Climate'.
[137] Information provided by Munich Re
[138] Kinrade, Carr, and Riedel, 'Wamberal Beach Management Options: Cost Benefit and Distributional Analysis'.

	Land Value Loss	Structural Damage	Land Value Loss	Structural Damage	Structural Damage
Lower Warming (RCP2.6)	$260m	$28m	$310m	$130m	$120m
Reference Case (RCP4.5)	$290m	$31m	$380m	$160m	$125m
Higher Warming (RCP8.5)	$350m	$39m	$560m	$230m	$135m

Heatwaves

Data

Climate data was sourced from the CSIRO and Bureau of Meteorology.[139] Data was available for regions across New South Wales and specified the number of days where temperatures were expected to exceed specific threshold values, in this case 32°C and 35°C. Projections were available for the reference case (RCP4.5) and higher warming (RCP8.5) scenarios from a range of GCMs, with CanESM2 selected as it matched one of those used in the agricultural modelling (see below).

Data on the location of workers for each of the four focus industries, agriculture, construction, manufacturing and mining, was sourced from the ABS (6291).

Projection method

The climate data was matched with labour force data to yield estimates of the proportions of each industry exposed to heat beyond the threshold values under the reference case (RCP4.5) and higher warming scenario (RCP8.5), with the proportions exposed under the lower warming scenario assumed to lie in between the reference case and current levels. Productivity loss functions were adapted from those used in the Garnaut Review.

Alternative productivity loss functions were considered but ultimately rejected due to both lack of data availability and their suitability for Australian conditions. For example, calculating "Wet Bulb Globe Temperatures" would require coincident projections of both temperature and humidity, which were not available.[140] Alternative damage functions projected steep declines in productivity at temperature thresholds already commonly exceeded through much of New South Wales, suggesting these may be better suited to European conditions, or less granular temperature information.

Agriculture

As noted in the main body, modelling of agricultural production was provided to Treasury by the CSIRO using their Land Use Trade Offs (LUTO) model. Detailed information on LUTO is available in a range of published research, including *Bryan* et al (2016).[141] Model settings were calibrated to reflect the broader assumptions in this assessment, and are outlined in the Table 11. Results reported

[139] 'Climate Change in Australia'.
[140] Roson and Sartori, 'Estimation of Climate Change Damage Functions for 140 Regions in the GTAP9 Database'; Tord Kjellstrom, 'Working on a Warmer Planet'.
[141] Bryan et al., 'Land-Use and Sustainability under Intersecting Global Change and Domestic Policy Scenarios'.

in the main body, and used in the CGE modelling, reflect a simple average of outputs from each of the two GCMs.

Table 11 LUTO modelling settings

Scenario Name	Global Outlook	GCM	Productivity Growth	Other Settings
Lower Warming	L1 (RCP 2.6)	MPI-ESM-LR / CAN-ESM2	Medium	Other settings relate to how quickly/easily land would be converted into carbon plantings or biodiversity uses and are therefore not relevant where no carbon price is in place to drive land use change.
Reference Case	M2 (RCP 4.5)	MPI-ESM-LR / CAN-ESM2	Medium	
Higher Warming	H3 (RCP 8.5)	MPI-ESM-LR / CAN-ESM2	Medium	

Application of shocks to VURM

The shocks applied to VURM are to agricultural production by industry and to all-factor technological progress by commodity. The latter is the instrument *via* which climate-change costs associated with natural disasters, sea level rise and heatwaves are introduced into the model.

Agricultural production is naturally model-determined (endogenous). To impose changes in agricultural production, we reverse the natural setting of the model, by making agricultural production exogenous and a previously naturally exogenous variable endogenous. The latter is all-factor (labour, capital and land) technological progress in agricultural production. Thus, exogenous changes in agricultural production are imposed via model-determined (endogenous) shifts in the productivity of factors (labour, capital and land) used in agricultural production.

It is assumed that climate costs associated with natural disasters, sea level rise and heatwaves affect the economy *via* technological deterioration in production across a range of sectors. As indicated already, technological change is naturally exogenous in VURM. Hence, changes in climate costs are imposed directly.

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