COMPOUND COSTS: HOW CLIMATE CHANGE IS DAMAGING AUSTRALIA'S ECONOMY

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Compound Costs: How climate change is damaging Australia's economy.

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Key Findings

1

Climate change is a major threat to Australia's financial stability, and poses substantial systemic economic risks.

- Direct macroeconomic shocks from climate change, including reduced agricultural yields, damage to property and infrastructure and commodity price hikes, are likely to lead to painful market corrections and could trigger serious financial instability in Australia and the region.
- Australia's financial regulators acknowledge that climate change is now a central concern for the economy and financial stability.

2

Detailed new modelling, based on the Federal Government's current approach to climate change, finds that the economic damage to Australia's property and agricultural sectors will be very significant.

- Australia's greenhouse gas emissions have been rising for four years and we are not on track to meet our weak 2030 emissions reduction target. If the world followed Australia's approach we would be on track for at least 3-4°C of global warming, which would have catastrophic economic consequences.

3

The property market is expected to lose $571 billion in value by 2030 due to climate change and extreme weather, and will continue to lose value in the coming decades if emissions remain high.

- One in every 19 property owners face the prospect of insurance premiums that will be effectively unaffordable by 2030 (costing 1% or more of the property value per year).
- Some Australians will be acutely and catastrophically affected. Low-lying properties near rivers and coastlines are particularly at risk, with flood risks increasing progressively and coastal inundation risks emerging as a major threat around 2050.
- Certain events which are likely to become more common because of climate change are not covered by commercial insurance, including coastal inundation and erosion.
- More than $226 billion in commercial, industrial, road, rail, and residential assets will be at risk from sea level rise alone by 2100, if greenhouse gas emissions continue at high levels.

4

Extreme events like droughts, heatwaves, cyclones and floods have an impact on agriculture and food production; this is already affecting Australia's economy and will cost us much more in the future.

- Climate change is increasing the severity and intensity of extreme weather events in Australia.
- On current trends, the accumulated loss of wealth due to reduced agricultural productivity and labour productivity as a result of climate change is projected to exceed $19 billion by 2030, $211 billion by 2050 and $4 trillion by 2100.
- By 2050, climate change is projected to halve the irrigated agricultural output of the Murray-Darling Basin region, which currently accounts for 50% of Australia's irrigated agricultural output by value (about $7.2 billion per year).
- By 2090, wheat yields on the 4,200 family farms in WA that produce half of Australia's wheat are projected to fall by 41-49% if greenhouse gas emissions remain high.
- Previous severe droughts have reduced Australia's Gross Domestic Product by around 1%; estimates suggest that increasing drought frequency and impacts in the future may reduce GDP by 1% every year.

5

The severe costs of climate change outlined in this report are not inevitable. To avoid the costs of climate change increasing exponentially, greenhouse gas emissions must decline to net zero emissions before 2050. Investments in resilience and adaptation will be essential to reduce or prevent losses in the coming decades.

- Increasing resilience to extreme weather and climate change should become a key component of urban planning, infrastructure design and building standards.
- Buildings and infrastructure must be built to withstand future climate hazards and to facilitate the transition to a net zero emissions economy.
- A credible national climate policy is needed to safeguard our economy by reducing the direct costs of climate change, and avoiding economic risks associated with a sudden, disruptive or disorderly transition to net zero emissions.

1. Introduction

There are few forces affecting the Australian economy that can match the scale, persistence and systemic risk associated with climate change.[1] Australia's financial regulators have recently made a call for action to deal with climate change, with the Reserve Bank of Australia, the Australian Prudential Regulation Authority and the Australian Securities and Investment Commission citing risks posed by climate change as a central concern for the economy and financial stability. As the Deputy Governor of the Reserve Bank of Australia noted, the risks that climate change poses to the Australian economy are "first order" and have knock-on implications for macroeconomic policy (Debelle 2019).

Australia's financial regulators have acknowledged that climate change poses significant and systemic risks to our economy.

Australia has always been a land of droughts and flooding rains. However, in the past, extreme weather events were cyclical around a stable average, allowing enough time for recovery between events. Now, climate change is driving a trend change, increasing both the frequency and severity of many extreme weather events (Climate Council 2019). This is shrinking the recovery times between events, and increasing the probability of simultaneous events in multiple locations. Climate change is also increasing the probability of compound events, where two or more extreme weather events combine to produce impacts that are worse than the effects of each event independently (e.g. coincident droughts and heatwaves worsening bushfires).

There are many examples of extreme weather and climate events creating supply shocks that reduce output, cause unemployment and increase prices and inflation. The agriculture sector is particularly sensitive to climate and weather, so despite being a relatively small sector (around 2-3% of Gross Domestic Product or GDP), the impacts of drought are apparent in aggregate GDP. Previous severe droughts have reduced economic growth by about 1% (e.g. the 2002-03 drought and the 1994-95 drought) (Commonwealth of Australia 2005). Extreme weather events can also generate supply shocks that push up commodity prices and increase inflation – for instance Tropical Cyclone Yasi drove up banana prices, boosting inflation by just under 1% (Debelle 2019). Inflation returned to normal the following season, but the prospect of near permanent supply shocks driven by climate change poses threats

[1] Systemic risks are imposed by interlinkages and interdependencies within a system, where the failure of a single component or cluster can cause a cascading failure, resulting in system instability and potential collapse.

If climate change continues unabated, extreme weather and climate events will increasingly cause economic shocks that will cascade through the economy.

to economic resilience. Climate change can also erode the productive capacity of the economy. For instance, funds may be diverted towards recovery and away from investments in new technology, machinery or research, leading to long-term reductions in productivity growth.

Climate change also presents broad risks to other sectors. Direct macroeconomic shocks will arise from the impacts of climate change on housing, temporary or permanent contractions of some industries and subsequent reductions in employment, commodity price adjustments, and damages and disruption to critical infrastructure that provide essential services and facilitate economic activity. Australia's economy will also continue to be affected by climate change impacts on our trading partners.

There has been recent media coverage and commentary on modelling that looks at the costs of deeper emissions reductions than the current Federal Government target of 26-28% by 2030 on 2005 levels. It is pointless to do this without actually looking at the costs of inaction. Studies such as the Garnaut Review (2008) and the Stern Review (2006) clearly show that the costs of inaction greatly outweigh the costs of action. Over the past five years, the Federal Government has squandered opportunities to tackle climate change, putting Australian lives, our well-being and the economy at risk. The longer we delay swift and decisive action, the more it will cost the Australian economy.

The modelling done for this report[2] shows that climate change is likely to result in sharp adjustments in residential property values in some areas. The total estimated damage-related loss of property value – excluding any disruptions to productivity – is expected to rise to $571 billion by 2030, $611 billion by 2050 and $770 billion by 2100.

These costs are likely to be highly concentrated on about 5-6% of properties, and will represent an enormous cost for those affected, with likely flow-on effects to the whole economy, as governments become the insurers of last resort. The annual average risk costs of extreme weather and climate change to properties is projected to rise to $91 billion per year in 2050 and $117 billion per year in 2100. These will be felt through increased insurance costs and will predominantly impact the same households that will experience the steepest losses in property values.

Failure to tackle climate change will also come at a cost to agriculture and labour productivity. The cumulative loss of wealth for Australia from the impacts of climate change on agricultural and labour productivity is expected to reach $4.2 trillion by 2100.

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[2] The methods and assumptions behind the modelling can be found in Annex A and B at the back of this report.

Figure 1: Australian properties have been battered by powerful storms in the past; as climate change intensifies property value loss could reach $571 billion by 2030. Impacts like coastal inundation are not covered by insurance policies.

The costs explored here represent a partial snapshot of some of the direct costs of climate change in a business-as-usual emissions scenario (i.e. if greenhouse gas emissions continue unabated). Three case studies are also presented to show the systemic nature of climate change costs, and how they may cascade through the economy, affecting households, governments and businesses. There are also many very significant costs of climate change that cannot be adequately captured through an economic lens, and have not been explored in this report. These include loss of life, health and wellbeing, reduced safety, and loss of species and biodiversity.[3] This report focuses on synthesising systemic impacts of climate change on the economy that have previously been very partially estimated, or have been greatly underestimated.

Decisions taken now will have major impacts on future climate trends and impacts. Until around 2050, a considerable increase in climate impacts is locked in from greenhouse gas emissions that have already been released. Therefore, it is important to ensure that well planned adaptation is underway at all levels now, within a strong framework that should be facilitated by government, but also involve the private sector. It is also important to accelerate the transition to a net zero emissions economy by 2050 at the latest and preferably much earlier, or else the costs of adaptation and residual loss and damage will increase rapidly after 2050. Steering the economy to net zero emissions through stable and credible policies is crucial for managing both the physical risks from climate change and the risks and opportunities associated with decarbonisation of the economy.

Climate change and extreme weather are projected to reduce property values by $571 billion by 2030, $611 billion by 2050 and $770 billion by 2100.

[3] Some costs to biodiversity have direct and quantifiable impacts. For instance, loss of the Great Barrier Reef due to climate change would mean loss of the reef's annual economic contribution of $6.4 billion per year (Deloitte 2017a). In other ways, the Great Barrier Reef is arguably priceless.

Cumulative damages to agricultural and labour productivity from climate change are expected to reach $4.2 trillion by 2100.

The Climate Council of Australia commissioned new modelling to inform the results outlined in this report. The modelling was conducted in two parts. First, damages from climate change to agricultural productivity and labour productivity were modelled using the Global Trade Analysis Project Computable General Equilibrium Model. The potential economic damages from climate change in this computational platform were limited principally to reduced agricultural and labour productivity, loss of arable land due to sea level rise and some health impacts. Results were obtained at various global temperature increases, and are presented in this report as the net present value of cumulative damages from 2017 at different points in time. More details on the methods can be found in Annex A. To incorporate impacts of climate change on the Australian property sector, a separate analysis was undertaken by the Cross-Dependency Initiative (XDI). This included an assessment of the 15 million addresses in Australia, with each property tested against six extreme weather hazards – flood, coastal inundation, bushfire, wind storms, heat-waves and soil subsidence. The number of properties was assumed to remain stable in the future, but the influence of climate change on the six hazards was modelled to assess annual average risk costs (used to inform insurance premiums) and property value losses. This assessment was one of the largest climate change risk assessments of property in Australia. See Annex B for more details on methods and assumptions.

Failure to act would result in significant economic damages. The Federal Government must implement credible climate policies that set us on a course for net zero emissions before 2050.

2. Modelling Results

The modelling scenario adopted in this report is one that assumes global greenhouse gas emissions continue to rise on a business-as-usual trajectory.

This scenario was chosen as it is the future that would eventuate if the world were to adopt similarly dismal levels of policy effort to Australia in addressing climate change. Australia's greenhouse gas emissions have risen over the past four consecutive years, and are set to continue to rise based on current policies. If the world were to adopt a similar policy trajectory to Australia, the global average temperature would increase by between 3°C and 4°C by the end of this century (CAT 2019), which is aligned with the highest emissions scenario outlined by the Intergovernmental Panel on Climate Change (IPCC) and used in this report. The purpose of highlighting the high emissions scenario is to illustrate that there are substantial costs associated with inaction on climate change. These costs are not inevitable. Many future costs could be avoided through credible policies that drive down greenhouse gas emissions to net zero by 2050 or earlier, and increase climate change resilience across society.

2.1 Impacts on insurance costs and property value in Australia

The property sector has a larger "footprint" on the Australian economy than any other industry (AEC Group 2015). The market for residential properties is valued at around $6.6 trillion (significantly larger than the Australian Stock Exchange and about threefold larger than the superannuation industry). Activities involved in facilitating the property industry (e.g. construction, architecture and engineering, banking, insurance and property and business services) directly contribute around 11.5% to GDP (AEC Group 2015). The property industry also contributes around 16% to revenues of governments at all levels via taxes, rates and levees (AEC Group 2015). The industry employs around 1.17 million Australians and at least 14.1 million Australians also have a stake in the industry via their super funds (AEC Group 2015).

INSURANCE COSTS WILL INCREASE

The probability of extreme weather events is increasing due to climate change, putting the economy at risk. Reinsurance companies like Munich RE have stated clearly that insurers cannot keep using the past as a guide to the future (Munich RE 2019). In the absence of adaptation, it is inevitable that insurance premiums will have to rise. Currently, not all hazards are covered by commercial insurance. Hazards such as bushfires, riverine flooding and storm damage are generally covered, but events such as coastal inundation, erosion, landslip and subsidence are all generally excluded, which means people and business are effectively self-insured against these hazards (or insured by the taxpayer). For example, 3% of properties are built on soils that can contract and break foundations in a severe drought. Ideally these important hazards will become included in standard policies, though this would also require higher insurance premiums. Assuming that these excluded hazards are incorporated into insurance policies, and accounting for the increased risks associated with hazards that are currently generally covered, modelling undertaken by XDI estimates that the annual average cost of damage from extreme weather and climate hazards to properties will rise to $85 billion in 2030, $91 billion in 2050 and $117 billion in 2100 (see Table 1).

Table 1: Annual average risks costs (used to inform insurance premiums) in 2030, 2050 and 2100.

	2030	2050	2100
Total annual average risk cost	$85 billion	$91 billion	$117 billion
Percentage of properties over 1% risk cost threshold	5.3%	5.5%	6.6%
Number of houses over 1% risk cost threshold	795,000 (1 in 19)	825,000 (1 in 18)	990,000 (1 in 15)

COSTS WILL BE HIGHLY UNEVEN

The major impact of this increased cost will be concentrated on about 5-6% of properties, which will experience average annual risk costs (used to inform the pricing of insurance premiums) that are effectively unaffordable (costing the equivalent to 1% or more of the property value per annum). This would be the equivalent of a person with a home worth $500,000 having to set aside more than $5,000 every year for extreme weather losses for the building alone (not including contents, consequential losses, and normal insurance items like house fires and burglary).

The results indicate that by 2030 about 1 in every 19 properties is projected to fall into this category, by 2050 about 1 in every 18 properties, and by 2100 about 1 in every 15 properties is projected to fall into this category (see Table 1). The properties in this category are not spread out evenly, but are instead concentrated in areas that are highly exposed to current and future hazards – like flooding, bushfires and coastal inundation – and that were not built to withstand such events.

These figures assume that the type, number and location of properties remains constant over time. This means that these figures are highly conservative. Building new properties in areas exposed to current and emerging hazards could substantially increase the number of at-risk properties. The Local Government Areas (LGAs) with the highest number of impacted properties tend to be urban LGAs that have a higher number of properties in total. To convey a normalised picture of the most impacted LGAs, Table 2 displays the top ten LGAs in each state and territory with the highest *percentage* of impacted properties by 2100, as a proportion of all properties in each LGA. See Annex C for additional analysis on the most impacted LGAs by total count of impacted properties.

If we don't rapidly reduce greenhouse gas emissions, by 2030 about 1 in every 19 properties could have effectively unaffordable insurance premiums.

Table 2: Top ten most impacted LGAs in each state and territory, by the percentage of impacted properties.

NSW	VIC	QLD	SA	TAS	WA	NT
Moree Plains Flood; Soil	Swan Hill Flood	Gold Coast Flood; Inundation	Mid Murray Flood; Inundation	Northern Midlands Flood	Upper Gascoyne Flood; Bushfire	Roper Gulf Flood; Soil
Coonamble Flood; Soil	Campaspe Flood	Ipswich Flood; Soil	Tatiara Flood	Launceston Flood	Exmouth Inundation; Bushfire	Central Desert Flood
Brewarrina Flood; Soil	Gannawarra Flood	Sunshine Coast Inundation	The Coorong Flood; Inundation	West Coast Flood	Beverley Flood	Victoria Daly Flood
Bogan Flood; Soil	Benalla Flood	Toowoomba Mixed	Naracoorte and Lucindale Flood	Break O'Day Flood; Inundation	Northam Flood	MacDonnell Flood
Edward Flood	Melbourne Flood; Inundation	Rockhampton Flood; Inundation; Soil	Robe Flood; Inundation	Central Highlands Flood	York Flood	Alice Springs Flood
Bourke Flood; Soil	Moira Flood	Western Downs Flood; Soil	Kingston Flood; Inundation	King Island Flood	Moora Flood	Unincorporated NT Flood; Inundation
Inverell Flood; Soil	Greater Shepperton Flood	Mackay Inundation	Mallala Flood; Inundation	Huon Valley Flood; Inundation	Karratha Inundation	Katherine Mixed
Narrabri Flood; Soil	Horsham Flood; Soil	Townsville Flood; Inundation	Murray Bridge Flood; Inundation	Devonport Flood	East Pilbara Flood	Barkly Flood
Murray Flood	Loddon Flood	Moreton Bay Inundation	Gawler Flood	Latrobe Flood	Nannup Flood	West Arnhem Mixed
Walgett Flood; Soil	Hindmarsh Flood; Soil	Brisbane Flood; Inundation	Barossa Flood	Meander Valley Flood	Port Hedland Inundation	Darwin Inundation

* Impacted properties are defined as those where the annual average risk cost is 1% or more of the property value by 2100. In Queensland, due to the large number of small LGAs, only LGAs with more than 10,000 addresses were included.

** This table has been updated from the original. In the update, we have removed the ranking as the differences between some LGAs in the top ten are marginal; All LGAs in the top ten are highly vulnerable.

Queensland has a disproportionate number of LGAs that will be highly impacted by climate change and extreme weather. In Queensland, 64% of LGAs have 10% or more of their properties with an annual average risk cost that is 1% or more of the property value by 2100. In the Northern Territory, 24% of the LGAs meet this definition and in New South Wales 28% of LGAs meet this definition. Table 3 displays these figures for all states and territories.

Table 3: Percentage of impacted* LGAs out to 2100 in each state and territory.

	2030	2050	2100
New South Wales	23%	23%	28%
Victoria	10%	15%	23%
Queensland	52%	52%	64%
South Australia	8%	8%	10%
Western Australia	11%	11%	12%
Tasmania	3%	3%	3%
Northern Territory	24%	24%	24%
Australian Capital Territory	Negligible	Negligible	Negligible

*An impacted LGA is classified as one where 10% or more of the properties will have an annual average risk cost that is 1% or more of the property value by 2100.

RELATIVE PROPERTY VALUES WILL DECREASE

Household budgets are not elastic. Extra money that is spent on insurance must come from spending less on something else. When considering lending for mortgages, banks look carefully at the annual costs of the borrower, including the cost of insurance. Therefore, banks in principle will have to lend less for houses with higher insurance costs. Thus, for two equivalent homes, the one that is more exposed and vulnerable to climate exacerbated extreme weather impacts is expected to decrease in value compared to less affected properties. There is some evidence that climate change is already altering property values in parts of the United States (such as Miami), where higher elevation properties are essentially worth more now, and increasingly will be worth more in the future (Keenan et al. 2018). Based on research commissioned from XDI for this report, the total estimated damage-related loss of property value – excluding any disruptions to productivity or physical damage or replacement costs of buildings – is expected to rise to $611 billion by 2050 and $770 billion by 2100.

Table 4: Damage-related loss in property values expected in 2030, 2050 and 2100.

2030	2050	2100
$571 billion	$611 billion	$770 billion

IT'S GOING TO GET UNCOMFORTABLY HOT

The number of days which are dangerously hot has been increasing since the 1950s. These are days when people experience heat stress, which can result in respiratory and cardiovascular illness and even premature death. The design of buildings has a strong impact on the cooling needs of occupants, and most existing dwellings in Australia are not able to adequately protect people from severe heatwaves. There are some known approaches for reducing heat gain in existing dwellings, but as these are not effective in all situations, air conditioning may be required to reduce the heat stress of occupants. In general, investing in improving the thermal comfort of existing dwellings that are unable to protect people from heatwaves is a cost-effective preventative health measure. The average cost of a single acute hospital admission costs the health system approximately $5,171 in Australia (IHPA 2019). When the health benefits are considered alongside the social, financial and environmental benefits of more sustainable housing, there is a clear case for investing in thermal and energy efficiency upgrades in existing buildings. For new buildings, significant opportunities exist to strengthen building codes to cost-efficiently improve energy and thermal efficiency performance whilst protecting occupants from increased heat stress. Urban planning and design can also significantly influence heat build-up in urban areas. Designing urban spaces to take consideration of heat gain in the first instance is much less costly than retrofitting spaces retrospectively.

Investing in improving energy and thermal efficiency of new and existing buildings has considerable economic and health benefits.

2.2 Impacts of rising temperatures on agricultural and labour productivity

Allowing greenhouse gas emissions to continue on a business-as-usual trajectory is not an economically and socially responsible option for Australia. If this were to occur, cumulative damages from reduced agricultural and labour productivity (including via some human health effects) would reach $19 billion by 2030 and $211 billion by 2050. Damages would ramp up dramatically after 2050, with cumulative loss of wealth between now and 2100 reaching $4.2 trillion or roughly $61,000 per person on average. This is assuming that the Australian population increases to over 60 million in 2100 (i.e. a smaller population increase would naturally imply an increase in per person damages). These figures only account for damages arising from reduced agricultural and labour productivity, loss of arable land due to sea level rise and some health impacts. Losses from riverine flooding, bushfires and other extreme weather events such as storms and tropical cyclones – which are all projected to rise in frequency and/or severity because of climate change, and are expected to substantially increase economic losses – are not included in these figures.

Neighbouring countries, many of whom are major trading partners with Australia, are projected to experience much more severe damages than Australia. Total cumulative damages to 2100 in Southeast Asia are more than $167 trillion. Losses in annual GDP in the region, starting in 2100, range from 12-21%, figures comparable if not exceeding the 15% reduction in worldwide GDP that occurred during the 1930s Great Depression – the worst economic downturn in the history of the industrialised world. By comparison worldwide GDP fell just 1% during the Global Financial Crisis in 2008-09 (Lowenstein 2015).

Failing to rapidly and deeply reduce our emissions would be economically and socially irresponsible.

CASE STUDY:

The cost of the 2009 heatwave across southeastern Australia

Climate change is making heatwaves in Australia more frequent, intense and longer lasting (Perkins and Alexander 2013). During the summer of 2009, southeastern Australia experienced one of the nation's most severe heatwaves. The heatwave was intense, prolonged and extensive, and was exceptional compared with 100-150 years of historical observations. The heatwave contributed to catastrophic bushfire danger conditions, and the occurrence of the devastating Black Saturday bushfire disaster. In the five to ten years leading up to the event, the Millennium Drought had gripped eastern Australia, leading to particularly dry soils and vegetation that were further desiccated by the heatwaves. The impacts of the heatwaves and subsequent bushfires were substantial. This case study outlines only the impacts of the heatwaves, the costs of which are poorly understood as they rarely result in permanent damage to infrastructure. However, impacts on health and service disruptions due to failures in critical infrastructure are substantial.

The heatwave during the summer of 2009 sharply increased heat-related deaths in vulnerable groups. As many as 500 excess deaths were recorded in Melbourne and Adelaide (374 deaths in Melbourne and 50-150 deaths in Adelaide) (QUT 2010). In addition, there were more than 3000 reports of heat-related illness (QUT 2010). Emergency services such as ambulance and paramedics, emergency treatment and mortuary capacity were under severe strain in both Melbourne and Adelaide (QUT 2010).

Electricity infrastructure did not cope well with the heat. The Basslink interconnector between Tasmania and Victoria shut down due to overheating, significantly compromising power supply (Victoria gets about 6% of its power supply via the Basslink). This coincided with a period of high demand for power and reduced efficiency of transmission due to the heat. There were also a number of heat-related faults in transformers, resulting in outages of major transmission lines (QUT 2010). Rolling blackouts were introduced to protect the grid. On the evening of January 30, more than 500,000 residents in Melbourne went without power (QUT 2010). System-

Figure 2: Emissions from the burning of coal, oil and gas are causing more frequent, intense and prolonged heatwaves in Australia. Heatwaves in Australia can be medical emergencies, resulting in an increase in emergency department presentations and excess deaths.

wide failure was narrowly escaped. Between 27-30 January, Adelaide also experienced rolling blackouts as demand reached record levels. The failure of the Basslink interconnector also affected Adelaide.

Melbourne's transport services were heavily disrupted by the heatwave, with faults in the rail system including rail buckling, malfunctioning carriage air conditioning systems and power failure to the city loop line (Osborne & McKeown 2009). More than one third of services had to be cancelled during the heatwave, with cancellations peaking on January 30. Over 28-30 January, 7% of train services in Adelaide were also cancelled due to the heatwave (QUT 2010). Melbourne's road transport system was also affected by traffic signal disruptions at 124 intersections in metropolitan Melbourne and three intersections in regional Victoria, with about 1% of roads affected by flushing (melting bitumen) (Natural Capital Economics 2018). Minor disruptions to port operations in Melbourne were caused by melting bitumen, overheating of hydraulics and loss of electricity, contributing to loss of productive hours from the workforce (QUT 2010; McEvoy et al. 2013).

Direct financial losses from the heatwave have been estimated at $800 million (QUT 2010). These arose from disruptions to electricity and transport services, and emergency services costs. The reduced labour productivity of people is by far the largest cost of heatwaves in Australia, at an estimated $8.7 billion per year (0.3-0.4% of GDP) (Zander et al. 2015). Climate change has already made heatwaves more frequent, more prolonged and more intense, and these trends are set to continue over coming decades.

Figure 3: Extreme heat can have significant impacts on infrastructure and essential services, such as electricity transmission.

CASE STUDY:

Costs of climate change to the food system

The total food value chain in Australia is a major part of the economy, worth about $230 billion in 2012-13, equivalent to about 13.6% of current GDP (Department of Agriculture 2014). One fifth of the value comes from production, and the rest is in processing, retail and net exports (ABS 2018a; ABARES 2018; Department of Agriculture 2014). It also employs about a quarter of a million workers, nearly half of them outside cities. Two thirds of our production is exported (14% of Australian goods and services exports), valued at around $45 billion (DFAT 2017).

Climate change is influencing all extreme weather events as they are occurring in a more energetic climate system (Trenberth 2011). Australia is one of the most vulnerable developed countries in the world to the impacts of climate change. Extreme events like drought, heatwaves, cyclones and floods affect both production and value chains. Droughts like the Millennium Drought in the 2000s reduced overall yields from the Murray-Darling Basin by about 20%, including the complete failure of some crops such as irrigated rice. This drought reduced agricultural income by 42% and employment by 70,000 people (a 15% reduction) (Commonwealth of Australia 2005); other droughts in the past 30 years have reduced jobs by 6,000 and farm incomes by 18% (Wittwer and Griffith 2011; Commonwealth of Australia 2005). Droughts reduce the viability of regional towns, and cause spikes in the rate of rural male suicides, by as much as 15% (Hanigan et al. 2012). Severe droughts are expected to become more frequent, especially across southern Australia (CSIRO and BoM 2015).

Figure 4: Major droughts in Australia have cut GDP growth and affected food prices.

Climate change will cause significant economic loss to agricultural heartlands such as the Murray-Darling Basin and the Western Australian wheat belt.

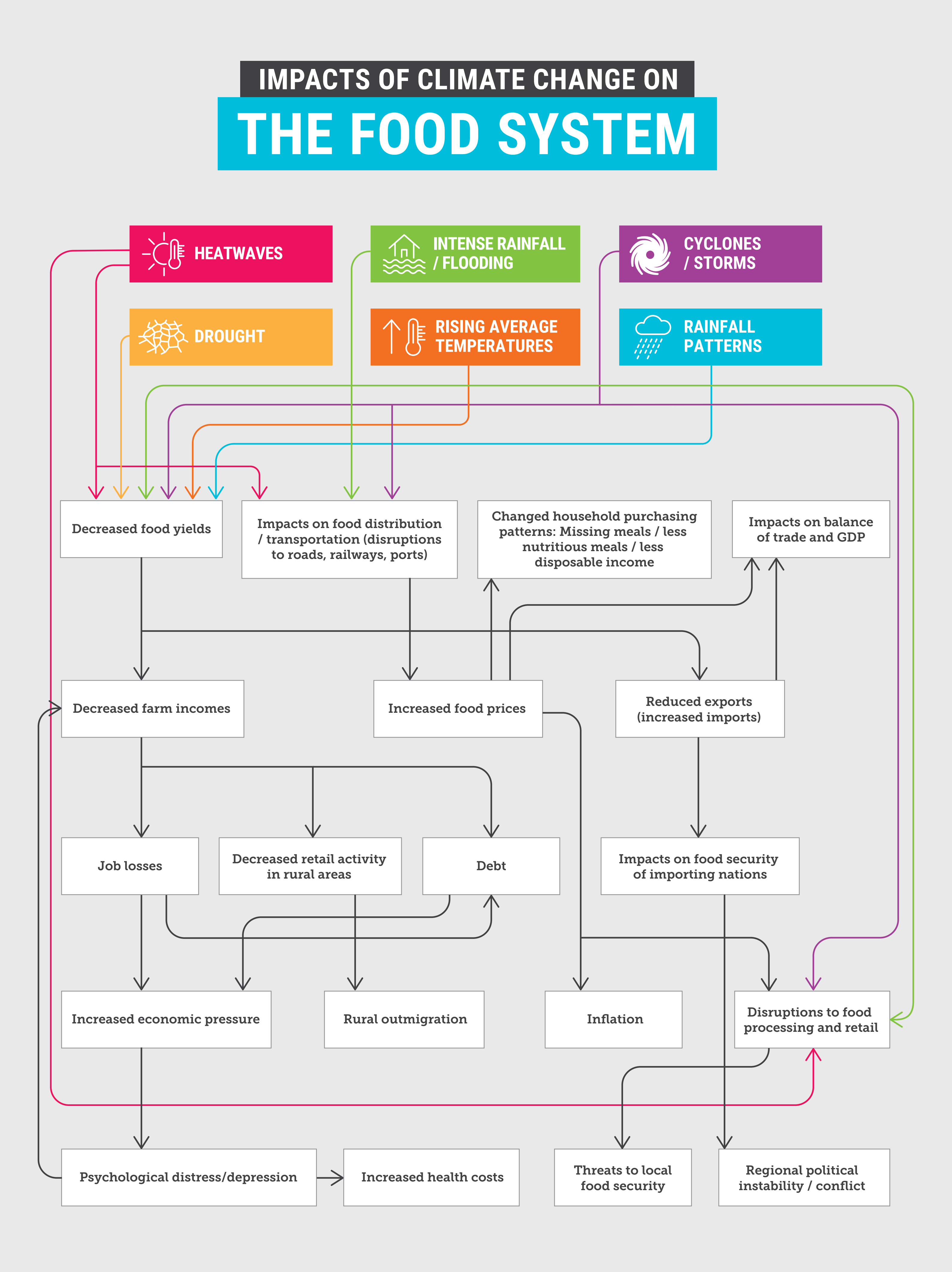
The 2009 Melbourne heatwave reduced apple and pear crops by 30-70% due to sunburn (Thomson et al. 2014). Based on the losses experienced in the 2009 heatwave event, the annual expected losses to agriculture from heatwaves is $39.3 million, rising to $109.5 million if greenhouse gas emissions continue at high levels (Natural Capital Economics 2018).

The 2011 and 2015 cyclones destroyed 70-90% of the Queensland banana crop, and the recent floods in north Queensland killed an estimated 664,000 cattle, worth an estimated $800 million (ABC 2019). Floodwaters can disrupt transport routes, interrupting supply chains and compromising food security, as happened in the 2011 Queensland floods when Rockhampton (population of 75,000) was cut off by road, rail and air for two weeks. Brisbane came within a day of running out of bread during the floods (DAFF 2012).

The food sector is also vulnerable to the more chronic effects of ongoing climate change, like rising temperatures, changing rainfall patterns, and the persistent damage caused by repeated extreme events. By 2050, without mitigation, we are projected to lose half the irrigated agricultural output of the Murray-Darling Basin (Garnaut 2008), which is currently worth about $7 billion per year and accounts for roughly half of Australia's irrigated agricultural production (ABS 2018b). By 2090 wheat yields on the 4,200 family farms that produce 50% of Australia's wheat in WA are projected to fall by 41-49% in the absence of reduced emissions, with shifts in rainfall patterns having the strongest influence on this decline (Taylor et al. 2018). Repeated extreme weather events can reduce agricultural productivity by reducing investments in new technologies and production efficiencies, leading to a permanent loss in productivity improvements that might otherwise help to counteract the effects of climate change. The 2000s drought was estimated to have reduced agricultural productivity by 18% through this effect (Sheng et al. 2019).

Droughts in the 1980s, 1990s and 2000s each shaved about 1% off national GDP growth in the years they occurred (compared to the global financial crisis in 2008-9 reducing GDP by 2%) (Commonwealth of Australia 2005; RBA 2006; World Bank 2015). Rural exports declined by 23% ($2 billion) during the 2002-3 drought, whilst overall food prices rose by 4.4%, twice the rate of the Consumer Price Index (Quiggin 2007). The current drought has already reduced farm output by 6% and total GDP by about 0.25% (Debelle 2019). Even if rainfall returns to normal soon, the impact of the drought will continue to exert a drag on the economy for some time. Federal drought assistance since 2000 has totaled around $6 billion, preventing these funds being invested in productive purposes such as research and development, innovation or infrastructure. Estimates of future drought frequency and impacts suggest an effective lowering of GDP by 1% every year (Carroll et al. 2007).

Figure 5: Impacts of climate change on the food system. **Source:** Authors.



CASE STUDY:

Costs of climate change on infrastructure

Significant costs can arise from the impacts of extreme weather on infrastructure. It is expected that around $17 billion (in present value terms) will need to be spent between 2015 and 2050 on rebuilding critical infrastructure following natural disasters (Deloitte 2017b).

Beyond direct damages to infrastructure that necessitate repair or rebuilding, significant flow-on costs arise from temporary disruptions to the functioning of infrastructure. Interdependencies between different types of essential urban infrastructure increase exposure to supply chain disruptions. For example, utilities such as electricity, telecommunications and water are necessary for the functioning of a range of other infrastructure.

There are already many examples of infrastructure failures due to the impacts of extreme weather events. In 2017, heatwaves caused 3,600 MW of power to fail in South Australia, New South Wales and Queensland during a critical demand period (14% of the total coal and gas fired power supply to these states) (Ogge and Aulby 2017). A major storm in South Australia in 2016 caused damage to electricity transmission infrastructure in the state (including bringing down 22 electricity transmission towers), which combined with other factors resulted in a cascading failure of the network and a power outage across most of South Australia. The disruption cost of the storm to businesses in South Australia was an estimated $367 million (with median losses of $5000 per business) (Business SA 2016).

The 2010-11 floods in Queensland disrupted commodity exports for an extended period, with a sizeable impact on gross state product. The floods inundated coal mines and rail lines and disrupted port operations, reducing coal exports for the first six months of the year. Queensland's total exports fell by 7.8% in 2010-11. The consequences of the floods reduced Queensland's overall growth in Gross State Product in 2010-11 by 2.8% (Queensland Treasury 2011). Flooding also prevented commercial shipping from the Port of Brisbane during 11-16 January (McEvoy et al. 2013).

Figure 6: Coastal erosion on the Gold Coast. Climate change exacerbates coastal flooding from a storm surge as the storm rides on higher sea levels, putting critical coastal infrastructure at risk.

Without action and as extreme weather events worsen, infrastructure companies are increasingly exposed to climate liabilities.

The exposure of coastal assets to sea-level rise associated with climate change is widespread and will increase in the future. More than $226 billion (in 2008 dollars) in commercial, industrial, road and rail, and residential assets are exposed to flooding and erosion hazards at a sea-level rise of 1.1 m.[3] Coastal assets at risk from the combined impact of inundation and shoreline recession include: between 5,800 and 8,600 commercial buildings, with a value ranging from $58 to $81 billion (2008 replacement value); between 3,700 and 6,200 light industrial buildings, with a value of between $4.2 and $6.7 billion (2008 replacement value); and between 27,000 and 35,000 km of roads and rail, with a value of between $51 and $67 billion (DCCEE 2011). Other national infrastructure within 200 meters of the coastline include: 120 ports, five power stations, 258 police, fire and ambulance stations, 75 hospitals and health services and 44 water and waste facilities (DCC 2009).

Some of these assets can be protected by coastal protection measures such as seawalls, but this will come at a cost. There is a lack of detailed and comprehensive research on what coastal protection measures are the most cost-efficient and effective for protecting assets along different areas of Australia's coastline, what these will cost, and how these can be financed, though some estimates exist for global coastal protection costs (e.g. Hinkel et al. 2014). Between now and 2100, population growth and poor urban planning could more than double the value of exposed assets and people at risk of impacts from shoreline erosion, storm surges and permanent inundation. Winds and intense rainfall associated with storms and cyclones also pose independent and linked threats to coastal infrastructure.

Banks, insurance companies and superannuation companies are heavily invested in properties and infrastructure in Australia, and these physical assets are increasingly exposed to the risks of climate change. Infrastructure companies may also increasingly face liability risks for contributing to risks related to climate change itself. In 2018 California's largest utility company, Pacific Gas & Electric Corp, filed for bankruptcy protection after faulty power lines were blamed for starting dozens of wildfires, including the Camp Fire – the most deadly and destructive in California's history. An insurance company also folded under the claims it received.

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[3] This is considered to be a 'high-end scenario' for 2100 based on projections from the IPCC's 2007 Fourth Assessment Report (AR4). However, this 'high end' projection is still highly plausible.

3. Conclusion and Recommendations

This report has provided a snapshot of the serious economic risks to Australia posed by unabated climate change.

It has highlighted the need for an in-depth study on this topic, to determine a more comprehensive picture of the likely economic costs of unabated climate change with no adaptive interventions, and what losses and damages can be avoided through a reform agenda led by government involving activities such as:

- Reducing emissions to net zero by 2050 or earlier, through clear and coordinated policy leadership.
- Strengthening building codes to increase the thermal efficiency and energy efficiency of buildings as well as ensuring building designs are fit-for-purpose to cope with increasingly frequent and severe climate-influenced hazards;
- Adopting risk-appropriate national land-use planning guidelines that prevent new buildings and infrastructure being constructed in areas that are, or will be, highly exposed to climate change hazards, and that help facilitate the reduction of emissions across the transport and buildings sectors;
- Upgrading and constructing new infrastructure (including infrastructure specifically designed to mitigate disaster risks), informed by a national assessment.

Such a study should also incorporate consideration of losses and damages that are unlikely to be able to be substantially mitigated through adaptation. For example, agriculture is a particularly climate sensitive sector, and limits to adaptation are already being confronted in this sector. Mitigation of greenhouse gas emissions is crucial to reduce impacts in this sector.

Given that buildings and infrastructure have long anticipated lifetimes (sometimes more than 100 years), it is critical that such assets are constructed not only to withstand future climate hazards, but to facilitate the transition to a low-carbon economy. This is also the case for land-use planning, which sets the direction for future investments in infrastructure and buildings, and which can substantially influence greenhouse gas mitigation possibilities in sectors such as transport.

The study above should be used to inform a revised and strengthened national climate and disaster resilience strategy and action plan that significantly scales up efforts to prevent hazards from turning into disasters, and increases disaster response capacity. Given that 90% of major disasters globally are due to climate-influenced hazards, it makes little sense to have separate strategies at the Federal Government level for climate and disaster resilience.

A national risk index should be developed to help compare the risk levels of different LGAs, as well as to track and evaluate risk over time. This will enhance understanding of the underlying causes of risk in specific areas, and help to inform locally appropriate risk mitigation options. Incentives should be devised to encourage coordination between public and private stakeholders to invest in cost-efficient and effective risk mitigation measures. Strategies that are common to clusters of LGAs may be appropriately implemented at higher governance scales. In many cases, broader co-benefits are likely to arise from investments in resilience, such as increased employment, increased business confidence and improved service reliability.

4. Annex A: Methods and assumptions of the agricultural and labour productivity analysis

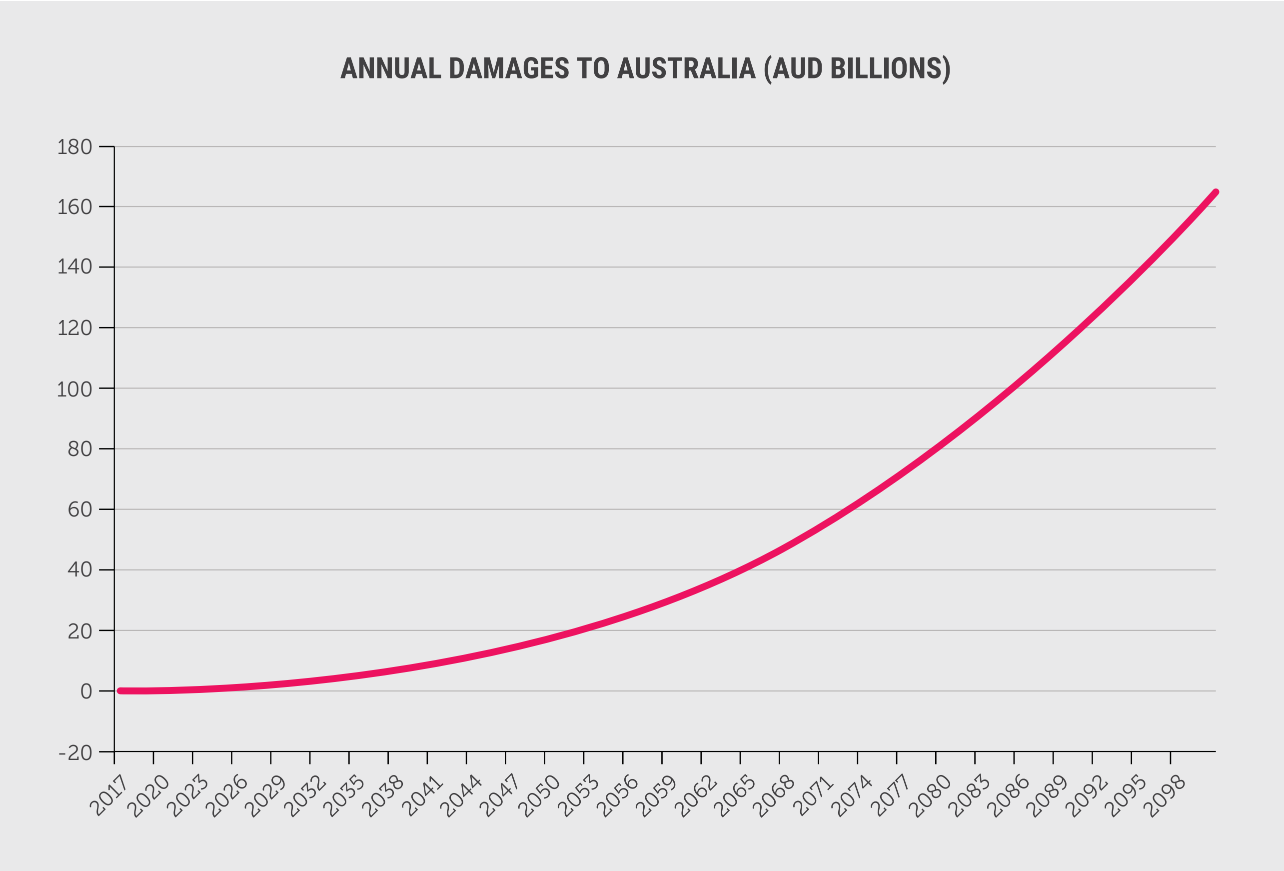
This study has built on previous work by Kompas et al. (2018) to ascertain cumulative damages from climate change from 2017 to 2100 for 139 countries and more than 50 sectors or commodity groups (using the Global Trade Analysis Project Computable General Equilibrium Model). Results were obtained at various global temperature increases (2030, 2050 and 2100).

The potential damages from climate change in this computational platform are limited, principally to reduced agricultural and labour productivity, loss of arable land due to sea level rise and some health impacts. Reduced agricultural productivity arises from a combination of variables, which are: increasing average temperature, shifting precipitation patterns, rising atmospheric carbon concentrations and sea level rise (through reduced supply of arable land). Reduced labour productivity arises from increased heat stress, measured using a heat stress index that takes both temperature and humidity into consideration. Impacts on labour productivity are modelled across three sectors: agriculture, manufacturing and services. Some additional health impacts are included via the impacts of temperature on a few disease types.

The damage functions used in this study are very limited. Losses from floods, bushfires, storms and tropical cyclones, which are increasing in frequency and/or severity due to climate change are not included. Other impacts of climate change on properties and infrastructure are also excluded, as are impacts on health via a range of other pathways. Losses from these impacts could be substantial. Notably, the model does not place any value on biodiversity and ecosystems, so these losses are not reflected at any point in the costed damages (not even through contractions of some industries such as nature-related tourism). Nevertheless, we know these costs could be substantial. For example, the Great Barrier Reef supports 64,000 jobs and contributes $6.4 billion to the Australian economy per year (Deloitte 2017a).

The work focuses on a time path for local temperatures that is consistent with a business-as-usual emissions trajectory (RCP 8.5) and draws baseline population and GDP projections from a socioeconomic pathway that assumes a doubling of global food demand, high level use of fossil fuels and a tripling of energy demand over the course of the century (SSP5). This is consistent with the highest greenhouse gas emissions pathway. Damages are expressed in ‘real terms’ using a 5% discount rate to convert future losses into current dollars. Values are expressed as the present values of cumulative damages up until each year (i.e. up until 2030, 2050 and 2100). Annual damages are presented in Figure 7 below.

Figure 7: Annual damages to the Australian economy from reduced labour productivity and agricultural productivity due to climate change.



5. Annex B: Methods and assumptions of the property impacts analysis

To calculate the impact of climate change on the property sector an assessment of all of the 15 million addresses in Australia was undertaken (PSMA 2019). Each property was tested against six extreme weather hazards – flood, coastal inundation, bushfire, wind storms, heat-waves and soil subsidence (the sinking or settlement of soil, which can occur as a result of drought and other factors, and which can affect building foundations).

The ability of the property to withstand an extreme event depends on the design, engineering and materials used in construction and so a high and low vulnerability test have been executed. In this study only the more conservative low vulnerability results have been provided – which assumes homes are recently constructed and built to reasonably modern design standards.

Looking forward, the number and type of properties is assumed to remain stable – so the possible effects of growth, planning law and design standards are excluded. The impacts of climate change have been based on a number of atmospheric models based on the IPCC RCP 8.5 scenario (e.g. MIROC3.2 and ECHAM5), which assumes greenhouse gas emissions continue to increase at least until mid-century. A sea level rise projection of 1.6m by 2100 was used, which is above the range in the IPCC's fifth assessment report (AR5), but about a metre lower than the upper range put forward by the US National Oceanic and Atmospheric Administration (NOAA) – this is to accommodate recent research regarding the greater significance of melting ice sheets (NOAA 2017).

To obtain more geographically accurate data we used Regional Climate Model (RCM) downscaling from the University of New South Wales and the University of Queensland, as well as high-resolution flood modelling data from Ambiental (UK) and laser elevation models from Geosciences Australia. Bushfire maps were drawn from the rural fire services (or equivalent) in each state and subsidence risk was drawn from state and national soil classification maps – climate impacts were computed by looking at the projected changes to the days of high Forest Fire Danger Index (FFDI). Coastal inundation data was based on national tide gauges, CSIRO modelling of wave height distributions and sea level rise projections using standard joint probability mathematics.

The financial impacts computed were based on the projected probability of damage to each element of each property (e.g. foundations, floors, electrical, rood etc.) and their replacement costs, for each of the hazards and for each year of the century. These costs were summed to provide an annual average loss for each property – the basis of an insurance premium. The costs for all properties was then aggregated at different points in time.

A property was classified as effectively uninsurable if the annual average loss exceeded 1% of the property value (for example an annual average loss more than $10,000 per year for a property worth $1 million). The results were aggregated to show the number of properties in this category in each local government area. Property value corrections were based on recalculating the size of the mortgage that could be serviced if the increased annual average loss was re-diverted to insurance premiums – based on current standard variable interest rates.

6. Annex C: Additional analysis on impacted LGAs

Table 5 below shows the results of additional analysis depicting the most impacted LGAs by the total count of impacted properties.

Table 5: Additional analysis on most impacted LGAs by total count of impacted properties.

NSW	VIC	QLD	SA	TAS	WA	NT
Parramatta Inundation	Melbourne Flood; Inundation	Brisbane Flood; Inundation	Mid Murray Flood; Inundation	Launceston Flood	Mandurah Inundation	Alice Springs Flood
Tweed Flood; Inundation	Port Phillip Flood	Gold Coast Flood; Inundation	Port Adelaide Enfield Inundation	Hobart Mixed	Karratha Mixed	Darwin Inundation
Newcastle Flood	Knox Mixed	Ipswich Mixed	Charles Sturt Mixed	Devonport Flood	Rockingham Inundation	Unincorporated NT Inundation
Central Coast Inundation	Mornington Peninsula Mixed	Sunshine Coast Inundation	Salisbury Mixed	Huon Valley Flood	Port Hedland Mixed	Roper Gulf Flood
Clarence Valley Flood; Inundation	Horsham Flood; Soil	Toowoomba Mixed	Marion Mixed	Glenorchy Mixed	Murray Flood; Inundation	Katherine Mixed
Lismore Flood	Campaspe Flood	Rockhampton Flood	Murray Bridge Flood	Meander Valley Flood	South Perth Inundation	MacDonnell Flood
Narrabri Flood; Soil	Greater Shepparton Flood	Western Downs Soil	West Torrens Mixed	West Tamar Flood	Perth Mixed	Barkly Mixed
Inverell Soil	Yarra Ranges Mixed	Mackay Inundation	Playford Mixed	Clarence Mixed	Bunbury Mixed	Litchfield Mixed
Richmond Valley Flood; Inundation	Swan Hill Flood	Townsville Flood; Inundation	Alexandrina Flood	Kingborough Mixed	Busselton Inundation	West Arnhem Mixed
Port Stephens Flood; Inundation	Moira Flood	Moreton Bay Inundation	Gawler Flood	Central Coast Mixed	Bayswater Mixed	Coomalie Mixed

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