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CSIRO Submission 17/602

Inquiry into current and future impacts of climate change on housing, buildings and infrastructure

Senate Environment and Communications References Committee

August 2017

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Executive Summary

CSIRO's research provides knowledge about climate risks and opportunities in a wide variety of sectors and informs options for improving resilience to climate impacts. We specialise in understanding systems and how cross-sectoral interactions add up to economy- and society-wide impacts. The challenges are big, and we would emphasise the importance of talking about responses (or solutions) at the same time as describing the problems, in order not to disempower action; in this submission we seek to meet this balance.

Climate change is likely to drive large, unprecedented, and systemic changes, which will have impacts on infrastructure. However, uncertainties remain about how climate change will play out over the long-term. A world-class global climate and earth system simulation capability, with regional skill and relevance, is critically important to inform complementary adaptation and mitigation strategies.

To tackle the systemic risks created by climate change, the most effective policy responses are likely to be flexible and take a systemic approach. That is, adaptation is likely to be most effective when it is not just about specific decisions or actions. A holistic approach that incorporates cross-sectoral, inter-disciplinary and multi-agency information is likely to achieve effective infrastructure adaptation, regardless of the magnitude and nature of climate change impacts. For example, a decision to require all large planning and infrastructure investments to consider future climate risks explicitly through an authoritative process would likely reduce systemic risks to Australians quite rapidly. Adaptation should employ modelling and new decision-making approaches to plan flexible, cross-sector pathways to increase resilience to multiple threats.

Adaptation and mitigation are complementary strategies for managing and reducing the risks of climate change. A strong foundation in policies, laws, institutions and research and technology will assist Australia to further reduce greenhouse gas emissions and build resilience of communities, the economy and the environment. Resources to assist decision makers – such as tools for integrated assessments of greenhouse gas emissions – may help inform decision making, policy implementation and new infrastructure developments, from individual dwellings up to the scale of major developments. There are also a range of gaps in approaches to adaptation which research and development can help to identify and address.

CSIRO suggests that for Australia to become well prepared for climate change effects on infrastructure that considerable attention is paid to understanding the systemic nature of interdependencies between elements of the infrastructure system, and the equally important interdependencies among the different decision making and implementing agencies responsible for infrastructure. CSIRO urges that the committee consider the system of infrastructure co-dependencies and complex interactions of indirect effects, mitigation and adaptation.

Introduction

CSIRO welcomes the opportunity to provide a submission to the Senate inquiry into current and future impacts of climate change on housing, buildings and infrastructure.

Our submission is based on CSIRO's relevant and rigorous science, products and services to help Australians understand, plan for, adapt to, and mitigate, climate change:

- We provide observations, analyses and assessments to understand the causes of current and past climate variability and long-term climate trends; we develop, test and use weather and climate models to deliver projections of climate change; and we conduct research into climate processes and the contributions of the oceans, atmospheric greenhouse gases and the carbon cycle to climate change and variability.

- Our research provides knowledge about climate risks and opportunities in a wide variety of sectors and informs options for improving resilience to climate impacts. We specialise in understanding systems and how cross-sectoral interactions add up to economy- and society-wide impacts. As a national research agency, we are committed to taking a nationally consistent approach to our research; building local research into a national perspective; and bringing together social, economic and natural science perspectives.

- We collaborate with other agencies and research providers and also maintain and leverage substantial international collaborations, linking into cutting-edge global research, and into global observation and modelling, bringing a global perspective on Australian issues.

- We work closely with governments, industry, non-government organisations and the community to develop practical and effective climate change response options, and provide advice that is based on peer-reviewed science.

Broader context and scope

This submission addresses the Senate inquiry's Terms of Reference below. In addition, as background information to support our submission we would like to provide an overview of work undertaken regarding potential actions and adaptation responses as follows:

Climate change is likely to drive large, unprecedented, and systemic changes in climate, which will have impacts on infrastructure. However, uncertainties remain about how climate change will play out over the long-term. CSIRO research affirms the principles described in Australia's National Climate Resilience and Adaptation Strategy, which can be stated as:

- Flexibility and adaptability have increasing value in policy responses (e.g. Wise et al., 2014; Stafford Smith et al., 2011)
- Existing societal goals, preferences and rules are likely to become increasingly ambiguous and unfit for purpose (e.g. Gorddard et al., 2016)
- Learning about how our infrastructure-related systems are changing and how to make different decisions becomes critical.

Systemic impacts and risks in an interdependent infrastructure system require a systemic response (Bai et al., 2016).

Adaptation and mitigation are complementary strategies for managing and reducing the risks of climate change. Mitigation strategies and actions reduce net greenhouse emissions and limit the longer-term extent of anthropogenic climate change. Substantial reductions in net greenhouse gas emissions over the coming decades will enhance the effectiveness of adaptation strategies and reduce the costs and challenges of mitigation in the longer-term (ACCSP, 2016).

Adaptation responses enable individuals, communities, organisations and natural systems deal with those consequences of climate change that we are already committed to and cannot be avoided by climate mitigation (i.e. reduced net greenhouse gas emissions). Adaptation can involve gradual transformation with many small steps over time, or major transformation with rapid change; the latter is likely to trigger additional 'transition risks' (PRA, 2015) through the rapid implementation of policy to handle crises. There are engineering and built-environment solutions, institutional solutions, technological solutions and ecosystem-based solutions. Some actions, such as energy-efficient building design, water conservation and urban greening, have both mitigation and adaptation co-benefits (ACCSP, 2016).

Of course, the impacts of climate change – and society's response to these – do not operate in a compartmentalised way. Infrastructure adaptation is likely to be most effective when considered holistically, and adaptation approaches are likely to be most effective when they incorporate cross-sectoral, inter-disciplinary and multi-agency information, regardless of the magnitude and nature of climate change impacts. Responses also need to consider connections between sectors, increasing information flow and overcoming institutional regulations, to possibly deliver multiple benefits and reduce the likelihood of maladaptation (O'Connell et al., 2015).

Similarly, mitigation and adaptation strategies need to be regarded in a complementary way, because the effectiveness of adaptation will be enhanced by effective mitigation. A world-class global climate and Earth System simulation capability, with regional skill and relevance, is critically important to inform these complementary adaptation and mitigation strategies because it enables future scenarios and consequences to be explored. One example of such a model system is Australia's ACCESS (https://www.csiro.au/en/Research/OandA/Areas/Assessing-our-climate/CAWCR/ACCESS) which simulates weather, climate, changes in atmospheric chemistry and the way that climate and the carbon cycle interact.

A 'systems view' of adaptation will help to reduce complexity and uncertainty of long time-scale adaptation by considering multiple factors such as decision lifetime, the uncertainty in the drivers of change and the nature of adaptation response options. That is, adaptation should not be just about specific decisions or actions (Stafford Smith et al., 2011). Indeed, 'deterministic decision-making' based on an individual hazard or scenario could be inflexible and fundamentally flawed for adaptation due to the uncertainty about the precise way in which hazards will change in future (Wang et al., 2014; Wise et al., 2014).

Adaptation responses are likely to be most effective if the focus shifts away from detailed impact and vulnerability assessments (which can lead to inaction or maladaptation due to detailed analyses providing different answers across scenarios) towards broader strategic assessments (Wise et al., 2014) that take account of multiple futures rather than the most likely or worst scenario. This approach employs modelling and new decision-making approaches to plan flexible, cross-sector pathways to increase resilience to multiple threats (e.g. Siebentritt & Stafford Smith 2016; CSIRO, 2017).

Adaptation to protect infrastructure can be associated with options to protect other assets that have environmental, societal or other non-monetary value, such as a beach. For example, hardening a sea wall (which may or may not be an appropriate adaptation option) can cut off other adaptation options, such as managed retreat (Wise et al., 2014). Conversely in appropriate places, adaptation options involving natural infrastructure, such as mangroves protecting coasts, may provide cheaper 'adaptation services' with greater co-benefits and future flexibility than physical assets such as sea walls (e.g. Colloff et al., 2016).

Adaptation responses can take a top-down approach, in which projections of future climate scenarios lead to an analysis of potential impacts, which in turn lead to specific adaptation actions, such as hardening infrastructure defences. Adaptation responses can also take a vulnerability assessment approach, where a consideration of values, rules and knowledge leads to the identification of social solutions, institutional restraints, barriers to change, and conflicts requiring resolution. Ideally, Australia's adaptation responses should involve a mix of both top-down and vulnerability assessment approaches, including 'no-regrets' options. General adaptation planning guidelines such as CoastAdapt (https://coastadapt.com.au/) or Climate Compass (CSIRO, 2017) provide evidence-based approaches to support implementation of these approaches.

Adaptation can be proactive (action taken anticipating what will happen) or reactive (taken after damage has happened). Different approaches are needed to address different impacts, and flexibility is required to adjust to changes over time. For example, proactive adaptation is often most economically advantageous to protect coastal infrastructure (Wang et al., 2016).

Climate change should not be considered separately from other drivers that require adaptation. Co-benefits can be achieved where adaptation also responds to pressures beyond climate change, such as increasing population density, depletion of natural resources, decrease in ecosystem diversity, and the increase of nutrients in water bodies (Nguyen et al., 2017; Rockström et al., 2009). Significant synergies and trade-offs exist between different adaptation responses, and also between mitigation and adaptation responses. Such interactions also occur both within Australia and between Australia and other countries (Reisinger et al., 2014).

There may also be options for better consideration of climate change risks and opportunities when assessing business cases for current and future infrastructure projects. Doing so is likely to contribute to better economic and social outcomes. More detail on the benefits of interconnected decision-making is included below.

CSIRO response to the Terms of Reference (ToR)

CSIRO's submission for ToRs (a) to (c) focuses primarily on projections of future climate, with some mention of observations of current climate change.

There are two important points to be made by way of context to CSIRO's responses to ToRs (a) to (c):

1. The magnitude and nature of multi-decadal to centennial climate change that the world is likely to experience depends strongly on actions to reduce the emissions of greenhouse gases. The Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) adopted four Representative Concentration Pathways (RCPs) to span the range of possible future trajectories in terms of the resulting greenhouse gas concentrations in the atmosphere. The four RCPs are RCP2.6, RCP4.5, RCP6, and RCP8.5; these are named technically after future radiative forcing values, but basically range from very low to high emissions pathways, and include the effects of burning fossil fuels as well as greenhouse gas emissions from land use change and industrial processes such as concrete manufacturing. The Paris Agreement goals are consistent with a future concentration pathway that falls between RCP2.6 and RCP4.5; whereas current commitments by countries are more consistent with the RCP4.5 trajectory at least until 2030 or so (UNEP, 2016). RCP4.5 is often referred to as an 'intermediate emissions scenario'. A continuation of historical emissions is more consistent with the RCP8.5 trajectory. Given there is not yet any certainty that the world will meet the Paris Agreement commitments, good risk management should consider this whole range of future climates.
2. In 2014, CSIRO and the Bureau of Meteorology published climate change projections for regional and coastal Australia, using the latest Global Climate and Earth System Models that participated in the most recent World Climate Research Programme's Coupled Model Intercomparison Project (CMIP5). These are the most up-to-date, nationally consistent, and comprehensive regional climate projections for Australia. They are publicly available at www.climatechangeinaustralia.gov.au.

a. Recent and projected changes in sea-level rise, and storm surge intensity

a1. Recent (observed) changes

Oceans surrounding Australia have warmed, with the greatest surface warming to the west and south of the continent (over 0.16 °C per decade) (CSIRO and Bureau of Meteorology, 2016). Over the past 200 years, there has been a 0.1 unit change in the ocean's surface water pH, representing a 26 per cent increase in the concentration of hydrogen ions in seawater (CSIRO and Bureau of Meteorology, 2015a). For 1966 to 2009, the average rate of relative sea level rise from observations along the Australian coast was 1.4 ± 0.2 mm/year (CSIRO and Bureau of Meteorology, 2015a). Sea level rise amplifies the effects of high tides and storm surges.

a2. Projected changes

It is through weather and climate extremes that most Australians will experience climate change. Advances in our ability to estimate 21st century climate will come from improving our knowledge on how phenomena that influence variability and extremes, such as the El Niño – Southern Oscillation and the Indian Ocean Dipole, are likely to change in future (e.g. Wang et al., 2017). This will allow for improved projections of likely changes to droughts, floods, frosts, heatwaves, fires, hailstorms, extreme winds, tropical cyclones and the monsoon (CSIRO and Bureau of Meteorology, 2015a). There will be environmental and economic benefits of improved nearer-term climate projections (that is, for the next decade or so) especially for changes in the intensity of extreme rainfall events.

Ocean thermal expansion and melting glaciers and ice caps were the main contributors to global mean sea-level change during the 20th century and are expected to be the major contributors during the 21st century, with additional influence from the loss of mass from ice sheets, and changes in the mass of water stored on land. As is the case globally, Australian sea levels are projected to rise through the 21st century, very likely at a rate faster than over the 20th century, including the past four decades (CSIRO and Bureau of Meteorology, 2015a).

The projected range of Australian sea-level rise by 2030 is 0.06 to 0.19 m above the 1986-2005 level (CSIRO and Bureau of Meteorology, 2015a). Different global greenhouse gas emission rates (i.e. RCPs, as described above) make only small differences to committed amounts of rising sea level over the next decade or so. As the current century progresses, sea level rise projections are sensitive to global greenhouse emissions. By 2090, intermediate global emissions (RCP 4.5) are likely to lead to a global sea-level rise of 0.27 to 0.66 m. High global emissions (RCP8.5) are likely to lead to a rise of 0.38 to 0.89 m. However, a collapse of the marine-based sectors of the Antarctic ice sheet could add several tenths of a metre to sea-level rise late in the century (CSIRO and Bureau of Meteorology, 2015b).

CSIRO's sea-level projections include 'allowances' that represent the height that coastal defences would need to be raised to ensure that they offer the same level of future protection as currently provided. Updated sea-level projections for Australia are available through the Climate Change in Australia marine explorer (https://www.climatechangeinaustralia.gov.au/en/climate-projections/coastal-marine/marine-explorer/#). There are projections for all 255 Australian coastal councils (via NCCARF's CoastAdapt web portal (https://coastadapt.com.au/tools/coastadapt-datasets#future-datasets).

Together with cross-shore impacts from changes to sea level and changes to coastal storms, variability and change in atmospheric circulation can alter direction of waves and the consequent longshore movement of sand. These longshore changes can affect beach shape by erosion or accretion and the stability of wave dominated entrances to sheltered coastal waterways (McInnes et al., 2016). CSIRO is identifying parts of the coastline that could be changed significantly because of a combination of these factors (e.g. O'Grady et al., 2015).

b. Recent and projected changes in temperature and precipitation

b1. Recent (observed) changes

- Australia's climate has warmed in both mean land surface air temperature and surrounding sea surface temperature, by around 1 °C since 1910 (CSIRO and Bureau of Meteorology, 2016)
- In recent decades, months warmer than average occur more often than months colder than average. And since 2001, the number of heat records in Australia has outnumbered extreme cool records by about 3 to 1 for daytime maximum temperatures, and about 5 to 1 for night time minimum temperatures
- The duration, frequency and intensity of extreme heat events have increased across large parts of Australia
- There has been an increase in extreme fire weather, and longer fire seasons, across large parts of Australia since the 1970s
- Australia's rainfall patterns have changed: i) May – July rainfall in SW WA has reduced by 19 per cent since 1970; ii) Growing season rainfall (April – October) has declined since the 1990s in the continental south-east of Australia; and iii) Rainfall has increased over parts of northern Australia since the 1970s
- Average snow depths have decreased at a number of Australian sites since the 1950s.

b2. Projected changes

CSIRO's research, conducted both globally and nationally, has improved our understanding of the way that climate change will affect extreme weather and climate events. This improved understanding enables us to explore with increasing confidence the consequences for regional and global climates across a range of scenarios of greenhouse gas emissions from human activities. There are two main uncertainties associated with the future climate projections: future anthropogenic greenhouse gas emission trajectories; and the response of the Earth's climate system to those emissions.

Regional climate projections provided by CSIRO and the Bureau of Meteorology through the Climate Change in Australia (CSIRO and the Bureau of Meteorology, 2015a and b) show that mean, daily minimum and daily maximum temperatures will continue to increase throughout this century for all parts of Australia. The magnitude of the warming later in the century will depend on global emissions. By around 2030, Australian annual average temperature is projected to increase by 0.6-1.3 °C above the climate of 1986-2005 under intermediate global emissions (RCP4.5), with little difference in warming between different emission (i.e. RCP) scenarios. The projected temperature range by 2090 is 0.6 to 1.7 °C for low emissions, 1.4 to 2.7 °C for intermediate emissions and 2.8 to 5.1 °C for high emissions. Inland areas are likely to warm more than coastal areas.

In southern Australia, winter and spring rainfall is projected to decrease, though increases are projected for Tasmania in winter (CSIRO and the Bureau of Meteorology, 2015a). The winter decline may be as great as 50 per cent in south-western Australia under high emissions by 2090. The direction of change in summer and autumn rainfall in southern Australia is uncertain, but there is medium confidence in a decrease in south-western Victoria in autumn and in western Tasmania in summer. There is medium confidence in a winter rainfall decrease across eastern Australia by 2090. In northern Australia and northern inland areas, there is low confidence in the direction of future rainfall change by 2090, but substantial changes to wet-season and annual rainfall cannot be dismissed.

c. Recent and projected changes in extreme weather, including heatwaves, bushfires, floods, and cyclones

c1. Recent (observed) changes

Hazards related to extreme weather have already changed in Australia, significantly in the case of duration, frequency and intensity of extreme heat events and fire weather (CSIRO and Bureau of Meteorology, 2016). Attribution studies have identified that recent heatwave events in Australia 2013 and 2014 are influenced by climate change. Oliver et al. (2017) found that recent extreme ocean temperatures observed in the Coral Sea and Tasman Sea, respectively, would have been very unlikely to occur in the absence of climate change.

c2. Projected changes

The natural climate variability that underlies all extreme weather events is now influenced by human-induced warming of the climate system (IPCC, 2012). Projected warming is likely to result in more frequent and hotter hot days (CSIRO and the Bureau of Meteorology, 2015a). For example, Sydney currently has around 27 days each year where the maximum temperature exceeds 30°C. By 2090, under intermediate global emissions of greenhouse gases (RCP4.5), there are likely to be approximately 51 days each year exceeding 30 °C; under high emissions (RCP 8.5), this is projected to rise to 84 days. The average longest run of Sydney days with maximum temperature exceeding 30 °C is currently around four per year. By 2090, under moderate (RCP4.5) emissions this will rise to around six days and under high (RCP8.5) emissions, nine days. Melbourne heatwaves are likely to increase from around four consecutive days annually exceeding 30°C to six or seven days by 2090, depending on emissions.

Heatwaves are projected to become more frequent, hotter, and longer across Australia by the end of the 21st century (Cowan et al., 2014).

Places where frost occurs only a few times a year now are projected to become nearly frost-free by 2030. Under high emissions (RCP8.5), coastal areas are projected to be free of frost by 2090 while frost is still projected to occur inland (CSIRO and the Bureau of Meteorology, 2015a).

Time in drought is projected to increase in southern Australia, with a greater frequency of severe droughts. This is consistent with the projected decline in mean rainfall. Time in drought is projected to increase in other regions, although there is less confidence in this projection than for southern Australia. The nature of droughts is also likely to change, with a greater frequency of extreme droughts, and less frequent moderate to severe drought projected for all regions (CSIRO and the Bureau of Meteorology, 2015a).

Projected warming and drying in southern and eastern Australia will lead to fuels that are drier and readier to burn, with increases in the average forest fire danger index and a greater number of days with severe fire danger (CSIRO and the Bureau of Meteorology, 2015a). CSIRO research helps with understanding links between extreme weather and bushfire (see ToR (j), below).

Throughout most of Australia, extreme rainfall events are projected to increase in intensity (CSIRO and the Bureau of Meteorology, 2015a).

Tropical cyclones are projected to become less frequent with a greater proportion of high intensity storms (those with stronger winds and greater rainfall) (CSIRO and the Bureau of Meteorology, 2015a).

The financial exposure of the Australian community and all levels of government to severe weather events affecting built infrastructure is large and rising. The economic costs of natural disasters, estimated to average $6.4 billion annually, are expected to double by 2030 and reach $23 billion by 2050 without accounting for climate change (Deloitte Access Economics 2013). Severe weather accounts for most of the estimated costs.

Further work is needed on quantifying future extremes. There is value in development of a standard national set of future climate scenarios with regional detail for local decision making.

Sea surface temperatures will also continue to increase. Sea surface temperatures around Australia are projected to rise, with the magnitude of the warming dependent on global greenhouse emissions. Near-coastal sea surface temperature rise around Australia is projected to be 0.4-1.0°C by 2030 and 2-4°C by 2090 under high emissions scenarios (RCP8.5) compared to 1986-2005 (CSIRO and the Bureau of Meteorology, 2015a).

Reflecting recent observations, the greatest warming is projected for marine regions off the coasts of Tasmania and south-western Australia, and off the northwest shelf. This background warming will lead to increased frequency and intensity of future marine heatwaves (Hobday et al., 2016), while changes in ENSO may influence the occurrence of marine heatwaves off Western Australia (Feng et al., 2015). As already noted, marine heatwaves are associated with shifts in species ranges and extinctions, along with economic impacts in fisheries industries (Hobday et al., 2016).

d. Recent and projected changes in natural coastal defence systems including coral reefs, kelp and mangrove forests

The long-term sustainability of coastal ecosystems such as coral reefs, salt marshes and mangroves are vulnerable to the effects of climate change. The effect of climate change on heat extremes – in the land and oceans, superimposed on ocean warming, on coastal and marine ecosystems has already been mentioned. Mangrove forests are also vulnerable to rising sea levels and changes in other factors such as the water balance and sediment supply (Lovelock et al., 2015) that are affected by climate variability, climate change and land management. These communities are also important in sequestering carbon and mitigating climate change.

Heatwaves are a feature of Australia's marine environment (Pearce and Feng, 2011; Oliver et al., 2017). These marine heatwaves have significant consequences for marine biodiversity (Wernberg et al., 2013) as well as productivity in aquaculture and fisheries industries (Perkins-Kirkpatrick et al., 2016). Ocean warming 'hotspots' have been identified in SE and SW Australia (Foster et al., 2014), and the Tasman Sea (Holbrook and Bindoff, 1997; Ridgway 2007). Climate extremes have resulted in widespread coral bleaching events in Australia over the past 5 years (Evans et al., 2017). Cyclone Yasi also caused significant damage to the Great Barrier Reef in 2011 while the strong El Niño event in 2015–16 also resulted in widespread bleaching of corals. While coral bleaching events are linked to climate variability and extremes, such as El Niño – Southern Oscillation and tropical cyclones, they are superimposed on increasing temperatures driven by global warming, causing bleaching of corals, loss of kelp forests, fish and invertebrate deaths, and changes in species distribution in western Australian marine environments (Evans et al., 2017). Since the 1980s, rising sea surface temperatures owing to global warming have triggered unprecedented mass bleaching of corals, including three pan-tropical events in 1998, 2010 and 2015/16 (Hughes et al., 2017).

The 2016 State of the Environment (Evans et al., 2017) reported that 'Sea surface temperatures are continuing to increase, with surface ocean warming during the 21st century occurring at approximately 7 times the rate observed during the 20th century. The frequency of extreme sea surface temperature events has increased. Rising summer ocean temperatures are increasing the extent of coral bleaching. Climate change is also resulting in ocean acidification and changes to ocean currents. In response to changes in the marine environment associated with climate change, there have been significant shifts in the ranges of various invertebrates and fish.

The oceans are absorbing more than 25 per cent of atmospheric carbon dioxide emissions. In the oceans, carbon dioxide dissolves, reducing carbonate concentration and seawater pH. This is known as ocean acidification. Oceans around Australia will become more acidic, at a rate proportional to carbon dioxide emissions. Acidification and higher ocean temperatures are likely to harm marine ecosystems (CSIRO and the Bureau of Meteorology, 2014) and the services they provide.

e. Impact on the vulnerability of infrastructure in coastal areas

e1. Current and future impacts of changes

Chen et al. (2017) note that sea level is now rising at a rate that is 50 per cent higher than prior to 1993. With coastal areas subjected to increasing sea-level rise in future, vulnerability of infrastructure will increase. In addition to rising sea level, projections suggest a greater proportion of severe tropical cyclones, with more extreme wind gusts. Hence infrastructure, particularly in Australia's north, needs to be strengthened or designed to be more resilient to tropical cyclones (Wang et al., 2013).

Under the current climate, structures around Brisbane and Newcastle may experience higher gust hazards than they are designed for (Wang et al., 2013). Most infrastructure is designed to be used for 50 years or longer, during which climate will change. Australian design standards may need to be reviewed and, if appropriate, revised to better reflect projected hazards; better-adapted coastal infrastructure will reduce wasteful repairs and replacement costs (e.g. Wang et al., 2016).

CSIRO undertook a preliminary assessment of the costs and benefits of proactive, planned adaptation on built infrastructure in south-east Queensland, which faces a high risk of inundation. An estimated 227,000 buildings are at risk of inundation from a 1-in-100-year storm tide. If the region's population does not change, sea-level rise could see this number increase to 245,100 by 2030 and 273,000 by 2070. However, the population is expected to increase to 4.4 million by 2030, compounding the impact of climate change if the population remains at its current pattern of settlement. South-east Queensland may experience greater inundation damage if there are no adaptation measures. By 2030, with an additional 0.2 m sea-level rise and unchanged planning and building regulations, the number of residential buildings at risk from a 2.5 m storm tide will increase from 35,200 to about 61,500. In 2070, such a storm tide will affect approximately 121,000 residential buildings (Wang et al., 2014).

e2. Response options

From a variety of studies in Australia and around the world (e.g. Deloitte Access Economics, 2013, Mechler 2016, Wang et al., 2016), there is growing evidence that adaptation costs for infrastructure are typically around 10 per cent of the benefits gained from avoided damages, even when the benefits are discounted over time.

There are three types of risk management options to adapt Australian coastal residential buildings to future coastal inundation hazard, mainly by storm surge and rising sea level (Wang et al., 2016):

- 'Avoid' options, which involve building housing in locations where the climate hazard is much reduced, or limiting new developments in hazardous areas
- 'Accommodate' options, which involve designing buildings in a way that makes them less vulnerable to climate hazards (e.g. strengthening roof construction to be more resilient to extreme winds, raising house floors in areas subject to flooding to, for example, heights of 100-year events)
- 'Protect or defend' options, which involve works that shield buildings from climate hazards (e.g. construction of flood levees and sea walls.

To implement planned retreat, changes to coastal governance would be needed (Abel et al., 2011). Adaptation approaches should invoke adaptation pathways (e.g. Wise et al., 2014; Siebentritt and Stafford Smith, 2016), where options for different scenarios are left open, and different trigger points prompt consideration of swapping pathways. With limited resources, not all infrastructure can be designed to be resilient to all scenarios, so analyses need to advise which infrastructure needs to be designed and built to what scenarios, or how to make assets robust across many scenarios (Stafford Smith et al., 2011), and how to assess these in economic terms (Wise and Capon, 2016).

Decision-support tools can help in assessing the climate risks in regions or sectors, and to support the development and communication of adaptation strategies. For example, CSIRO's AdaptNRM (2014) tool helps natural resource managers develop climate-ready plans (Australian Climate Change Science Programme, 2016). CSIRO Data61 is developing an integrated adaptation framework called C-FAST (City based Flood Adaptation Solutions Tool). The tool helps cities at risk from coastal inundation and flooding events manage urban flood emergencies, identify community flood risk, and improve infrastructure investment decisions (Cohen et al., 2016a). C-FAST has been used to consider longer-term adaptation approaches in flood-prone areas such as Elwood, Victoria (Prakash et al., 2015). 3D visualisation can help communities see the benefits of adaptation strategies (Cohen et al., 2016b). CSIRO has also contributed to NCCARF's CoastAdapt on-line system (https://coastadapt.com.au/), another source of advice in coastal areas.

CSIRO modelling helps decision makers determine options for adapting coastal residential buildings to future climate change under considerable uncertainties, including options, timing, and location of sensitive regions. For example, constructing new buildings with higher floors is a relatively inexpensive way of reducing future damage losses of storm-tide inundation, and is insensitive to uncertainties (Wang et al., 2014).

However, there is insufficient data for sophisticated urban modelling. There may be benefits from having a standardised nationwide high-resolution information, including tide, rainfall and terrain data, engineering infrastructure information, and local-scale climate projections. There may also be benefits from having a consistent aggregation of data on the costs and benefits of different adaptation measures such as hardening buildings against fires, floods and high winds, or different planning and development options in the face of sea-level rise; at present there is a growing amount of data but often disaggregated and inconsistently analysed with regards to costs and benefits over time, or in other ways not readily accessible to infrastructure decision makers and investors (see O'Connell et al., 2015).

f. Impact on water supply and sewage treatment systems

f1. Current and future impacts of changes

Water resources are vulnerable to both climate variability and change; for example, runoff into Perth's reservoirs has declined by 55 per cent since the 1970s, and the 1997 to 2009 Millennium drought resulted in unprecedented decline in runoff and water use in the southern Murray–Darling Basin and Victoria (Chiew et al., 2014; CSIRO, 2012).

Most of the runoff in far southern Australia occurs in winter. The projected decline in future winter rainfall in southern Australia will be amplified in the river flows (see section b2). Climate change by 2030 will reduce average river flows by 10 to 15 per cent (medium estimate) in south-eastern Australia, and by 20 to 30 per cent in the far south-west (Chiew and Prosser, 2011; Hope et al., 2017). The gap between water supply (projected decline in southern Australia) and water demand (higher demand from higher potential evaporation) will also increase. Without adaptation, this will likely significantly impact water security for irrigation, industry and the environment (Reisinger et al., 2014).

Wastewater treatment operates more efficiently at higher temperatures, but with a warmer climate there is concern that there will likely be an increase in antibiotic resistance genes and bacteria carrying virulence genes, such as *E. coli* (Sidhu et al., 2017).

f2. Response options

Solutions for reducing water consumption in urban areas with co-benefits for climate change adaptation and mitigation (e.g., greening cities and recycling water) are already being implemented, with planning for reduced water use in southern Australia adopted widely (Reisinger et al., 2014). Continued attention to demand management in the face of a growing population will be important.

Water planning is traditionally based on historical rainfall, runoff, and groundwater recharge data, but future water resource management and planning cannot rely on historical data as these are not a reliable guide to future water availability and water use (Chiew et al., 2014). Most state agencies now consider climate change in urban and regional water supply and demand planning, and improved hydroclimate projections are key inputs for these planning tools and risk management frameworks (Chiew and Prosser, 2011; Ekstrom et al., 2016).

Effective adaptation to longer and more severe droughts, and more intense rainfall events, will likely require consideration of water storage infrastructure design specifications. Recharging aquifers by capturing stormwater may become an increasingly important adaptation response to drought. Aquifers are low-cost and high volume, require less energy, are suitable from village to city scale supplies and lose little to evaporation (Dillon et al., 2010).

Wastewater treatment plants may need to be used to recycle more water within existing health guidelines (Sidhu et al., 2015). Many sewer systems and treatment plants were designed and built in wetter times – such systems may need to be modernised to cope with increased rainfall intensity and drought. Other approaches to improving water security, such as through use of decentralised systems at suburb or other scales, to improve resilience before future periods of water stress may become increasingly important.

Depending on the method of wastewater treatment, the need to sanitise and remove nutrients from wastewater can be both energy intensive and contribute to greenhouse gas emissions. However wastewater treatment can be adapted to produce energy (using anaerobic digestion) and to reduce greenhouse emissions. Wastewater may also be viewed as a climate independent source of water, with over 2000 GL treated in Australia (National Water Commission Data, 2012-13). Given these substantial volumes, the wastewater industry is responsible for managing over 95 per cent of the entire mass of waste coming from our urban environments (National Waste Report (2010) and National Water Commission Performance Report (2012-13). CSIRO conducts research on the integrated value of wastewater as a resource for water, energy and nutrients for productive agriculture (Burgess et al., 2015; Beale et al., 2016).

g. Impact on transportation, including railways, roads and airports

g1. Current and future impacts of changes

High temperatures can cause buckling of railways (Nguyen et al., 2011).

The risks to, and impacts of extreme environmental events on, Australia's roads include flash flooding, coastal flooding, higher temperatures and heatwaves (Taylor et al., 2015), implying greater repair costs and/or costs associated with designs that are resilient to increased extreme events.

Greater urbanisation means increasing complexity and infrastructure interdependencies in the delivery of urban services such as energy, water, transport and communication (Hasan and Foliente, 2015). Coinciding extreme events could potentially cause a range of impacts on infrastructure, leading to escalating events that are more challenging than the original event.

Furthermore, increasing resilience in one area may reduce resilience in others. Efforts such as the Trusted Information Sharing Network (TISN) for critical infrastructure resilience have attempted to address this, however interdependency is not always considered among infrastructure owners, so complex infrastructure interdependencies may need to be assessed – and dealt with – to make cities more resilient (Hasan and Foliente, 2015).

g2. Response options

An integrated systems approach is required across sectors to account for interdependencies and avoid possible cascading of failures in services during extreme events, especially in cities. For example, CSIRO is working with the City of Melbourne to assess the exposure to heat stress of a range of metropolitan systems, including local transport networks, healthcare systems, energy and water utilities, and other local support networks, including interdependencies between them. The work will provide a scientific basis for councils to understand risk, and will help develop recommendations to reduce vulnerability and support integrated planning and decision-making (City of Melbourne, 2016).

Similarly, CSIRO has developed the Adaptive Value Chains tool (https://adaptivevaluechains.com/) as a general approach to help businesses consider their value chain risks, and approaches such as Climate Risk's Cross Dependency Initiative (https://www.climaterisk.com.au/) are promising, but would need to be mainstreamed to reduce interdependency risks in infrastructure.

The risk of heat to roads could potentially be reduced by using heat-resistant materials, and sealing dirt roads to prevent inundation damage. However, improved planning, risk assessment and standards are more cost-effective than measures requiring physical changes to construction or maintenance practices (Taylor et al., 2015). That is, in appropriate cases, building adaptive capacity in people through education and awareness can be a more cost effective (and no-regrets) adaptation approach than hard engineering solutions.

There is a need to consider the implications of increased extreme climate events, particularly heat stress, when planning for more sustainable transport behaviour (Karner et al., 2015). Vulnerable population groups, such as poor households and the disabled, are more likely to be dependent on public transport (Lucas et al., 2016), and therefore exposed to climate risks posed by transit systems that are maladapted to a warmer climate. There is need for integrated planning for managing the climate risks associated with sustainable transport that considers the relationships between urban form, travel behaviour, land use and public health (Karner et al., 2015).

Risk to impacts and benefits of adaptation are not distributed evenly between levels of government or across jurisdictions, with coastal Australia having disproportionally more roads at risk. This raises issues of equity in terms of who should bear the cost of adaptation (Taylor et al., 2015).

h. Impact of these changes on energy infrastructure, including generators and transmission and distribution lines

h1. Current and future impacts of changes

With increased temperatures – particularly runs of very hot days – there will likely be greater use of air conditioning, increasing the electricity network's required generational capacity to meet peak summer demand (CSIRO, 2013). The peaks in summer electricity demand (in all states except for Tasmania, where winter peak demand is higher than summer) dictate the maximum capacity of the electricity system; greater capacity will be needed to cope with increased peak summer demand in the absence of other adaptations.

In a warming climate, severe wind events may become more intense and more frequent (CSIRO and Bureau of Meteorology, 2015a). Electricity transmission networks have experienced significant impacts under current climate, as exemplified by the Black System in South Australia after the severe storms of 28 September 2016, which resulted in five transmission system faults and 23 toppled transmission towers (AEMO, 2017). With possible increase of renewables in the generation mix, new and existing transmission lines may be built for resilience to cope with the changing wind storm climates. Electricity networks need to plan for the likelihood of more frequent and intense extreme weather events as a result of climate change. Coastal energy infrastructure faces risks, including frequent or permanent inundation in some areas. Preliminary modelling indicates it could cost every consumer an additional 2.8 cents per kilowatt hour by 2050 to adapt the current electricity supply chain to climate change (CSIRO, 2013).

Electricity transmission power losses rise by more than 50 per cent due to increased demand during heatwaves (Nguyen et al., 2011). Powerlines are likely to be vulnerable to bushfires, and electricity generators with open cut mines may need to close during fire periods. The increased temperatures on hot days plus the heat resulting from increased power passing through the lines limits the capacity and performance of electricity generation (Nguyen et al., 2011). Gas turbines, conventional thermal generators and solar panels have lower efficiency as they get hotter, and batteries can combust at temperatures of around 40 degrees so need a fan, which increases power use (Cavanagh et al., 2015).

Decreased water availability could affect the cooling of conventional thermal generators, although emission reduction policies are reducing the likelihood of construction of new coal-fired power stations (Graham et al., 2008).

Increasing use of energy sources such as wind turbines leads to uncertainty about financing and operation of Australia's electricity system due to uncertainty about the output under changing weather (Pryor and Barthelmie, 2011).

h2. Response options

Managing demand to enable more flexible capacity is an important way of adapting to a more variable supply and load. Demand management can be achieved through:

- Battery energy storage (Brinsmead et al., 2015);
- Heat storage in materials such as molten salts and pumped hydro (Campey et al., 2017);

- Incentives to reduce electricity use, such as discounts on electricity bills to compensate for decreased comfort (e.g. https://www.energex.com.au/home/control-your-energy/positive-payback-program/positive-payback-for-business/air-conditioning-rewards);
- Distribution network and retail pricing reform to establish greater opportunities for small customers or their agents to provide a range of demand management services to different parts of the grid (CSIRO and Energy Networks Australia, 2017).

i. Impact on health, education and social services infrastructure, including hospitals, schools and aged care

i1. Current and future impacts of changes

Extreme events such as heatwaves, storms and floods are likely to have a direct impact on the health of Australians, potentially causing an increase in heat-related deaths. Indirect impacts of climate change may occur through infectious diseases and physical processes such as air pollution or altering insect activity, increasing vector-borne diseases. For example, Australia can expect an increase in disease due to the spread of insect vectors, with 0.6 to 1.4 million more people exposed to dengue fever by 2050, as well as a rise in waterborne and food-borne diseases (Beebe et al., 2009).

The association between temperature and years of life lost is U-shaped, with increased 'years of life lost' (an indicator of premature mortality) for cold and hot temperatures. This pattern occurs because the increased heat-related years of life lost are offset by the decreased cold-related years of life lost. For a 2 °C increase, CSIRO projects a total increase of 381 temperature-related years of life lost in Brisbane, as the decreases in cold-related years of life lost will not offset the increases in heat-related years of life lost. Assuming a 4 °C increase, the health consequences become catastrophic without any adaptation to higher temperatures, with a projected net increase of 3,242 temperature related years of life lost in Brisbane alone under this future possible climate (Huang et al., 2012; population and demography were held constant at 2006 values).

i2. Response options

Cities are typically warmer than their surroundings – especially at night and under calm conditions, and these elevated urban temperatures are superimposed on the effects of global climate change on daytime mean, minimum and maximum temperatures and heatwaves. Research has shown that a combination of building and urban design can be used to passively moderate urban microclimates, and therefore urban warming. This is a key way for cities to both adapt to, and mitigate (through less energy used in air conditioning) global climate change (Cleugh and Grimmond, 2012).

The use of urban vegetation is one possible approach to passively modify urban warming. CSIRO modelling for Melbourne shows that average summer temperatures are 0.5 to 2 °C greater than if the region consisted of vegetated suburbs and parklands, respectively. Doubling Melbourne's vegetation coverage would reduce heat-related mortality by 5 to 28 per cent, while transforming the city into parklands would reduce heat-related mortality by 37 to 99 per cent (Chen et al., 2014).

j. Impact on private and public housing

j1. Current and future impacts of changes

Heatwaves that last for several days may have significant impacts on how buildings and infrastructure perform; specifically, how they maintain temperature for human comfort and safety, fire risk and utility failures. Heatwaves may significantly increase power load associated with air conditioners. Heatwaves have significant consequences for low-income households, with no means to abate the impact of heat (Barnett et al., 2013). Barnett et al. (2013) provide a national assessment of over 100,000 low income housing assets, identifying which of these have poor adaptive capacity in places where they may experience significant climate change impacts. There is the potential for similar issues to play out in the growing diversity of retirement and aged care facilities.

Losses are dominated by major bushfires that have occurred in severe weather (Blanchi et al., 2014). As noted in ToR (c) above, a greater number of days with severe fire danger is projected, hence a greater number of homes and lives may potentially be lost.

A CSIRO study of Queensland house and land values with and without storm surge exposure identified that the market devalues houses at the edge of the 1-in-100-year inundation region by 1.3 per cent, and houses within the region by an additional 5.3 per cent per metre of inundation during a 1-in-100-year event. Scaled up to national level, this suggests that even by 2030 the accumulated loss of land value is likely to be between $823 million and $1086 million (Fletcher et al., 2011; Rambaldi et al., 2013). This provides a context in which to assess the benefits and costs of adaptation options (see item j2 below).

Climate change will potentially affect concrete, a key component of much of Australia's infrastructure. Failure to consider the effects of climate change may compromise the safety of concrete structures in extreme events, but overcompensating may unnecessarily increase costs. Two major potential threats are: carbonation, which occurs when carbon dioxide penetrates the structure to expose steel reinforcements to corrosion; and corrosion caused by chloride penetration causing cracking, delamination, or spalling, of the concrete especially in marine and coastal areas. Both corrosion mechanisms are influenced by climate change –particularly, increasing temperatures and sea-level rise (Wang et al., 2010a).

Furthermore, CSIRO modelling has shown that some materials used in infrastructure could degrade 10-15 per cent more rapidly under a changed climate, including steel (Nguyen et al., 2013), concrete (Wang et al., 2010b) and timber (Barnett et al., 2013), depending on location.

j2. Response options

Adaptation to coastal inundation events to minimise damage to possessions and investments can include engineering responses (e.g. sea walls), building design responses (e.g. building floor height limits), and planning responses (e.g. staged retreat). In the long term, such options are likely to generate positive returns in high-risk areas (Fletcher et al., 2011). By assessing the distribution of risk across a community or suburb and calculating the potential value lost to extreme events, CSIRO has developed a process for deciding whether adaptation should be considered at the community level, the individual property level, or not at all, based on simple community characteristics and the distribution of risks and benefits (Fletcher et al., 2016).

Within the residential sector, the financial impact of inundation on land values due to changing coastal inundation regimes under future sea-level rise scenarios is expected to be of a similar magnitude to infrastructure damage by 2050. As such, consideration of appreciating lost land values as well as infrastructure damage is important to accurately assess the potential benefits of adapting coastal residential communities to coastal inundation. Correctly accounting for these potential benefits will likely strengthen the case for greater investment in adaptation, sooner (Fletcher et al., 2011; Rambaldi et al., 2013).

To enable adaptation and greenhouse gas reductions, housing design, energy ratings and building codes will likely need to take future climate into account over the life of the structure – that is, for construction, for retrofitting, and for human behaviour of occupants. While structures may be designed to historical climate standards, they need to withstand the climate of the future, and application of mechanisms for coping with extremes in climate (e.g. air conditioning) are likely to increase greenhouse gas emissions.

With increasing temperatures, housing may need to adapt through changes such as better insulation, window orientation and light-coloured roofs. CSIRO software to advise on compliance with the Nationwide

House Energy Rating Scheme (NatHERS) can help design housing that is adapted to a warmer world. However, the current focus is on the energy star rating rather than metrics relating to comfort and health, and over-emphasising building energy efficiency alone could potentially expose occupants to greater health risks during heatwaves (Ren et al., 2014).

Economic analysis of the likely changes in wind extremes in Queensland shows a ‘no regrets’ benefit of adapting houses or changing building codes now. Assuming ‘business as usual’ (no adaptation measures), a changing climate can increase mean cumulative wind damage direct losses (house and contents damage) for Cairns, Townsville, Rockhampton and south-east Queensland by up to $3.8, $9.7 and $20.0 billion by 2030, 2050 and 2100, respectively (assuming a 4 per cent discount rate). There is a high likelihood of large economic losses (especially in SE Queensland) if there is no change to building standards, with climate adaptation strategies needed to ameliorate these losses (Stewart and Wang 2011).

Similarly, regulations may need to be changed so that homes are built to cope with 2050 fire weather, rather than historical weather, including use of non-combustible materials and considerations beyond the external skin of buildings.

Green infrastructure – including urban vegetation and ecosystems – could potentially be considered alongside built infrastructure assets managed by councils, as vegetation can help reduce the impacts of extreme heat and urban heat island effect by decreasing temperature and reducing heat-related deaths (Chen et al., 2015; Lin et al., 2016). Putting a value on vegetation in cities (through the benefits of reducing heating/cooling requirements, reduced hospital emissions, etc.) could provide cost-benefit information to help to build the business case for climate adaptation.

Adaptation actions may be required for vulnerable populations in public housing, as a multiplier effect can occur where, for example, elderly or low income populations reside in unadapted public housing (Barnett et al., 2014; Bambrick et al., 2011). Adaptation options for social housing can include: mapping vulnerability of housing assets to better match at-risk tenants; identifying potentially dangerous properties for social housing authorities to transition out of as climate changes; and air conditioning as an option of last resort. No-regrets adaptation options such as changing roof colour, adding insulation, and draft-proofing may have the greatest benefit (Barnett et al., 2014). Similar options are likely to be applicable in the retirement and aged care sector.

k. Impact on public recreation and tourism facilities

Snow depths in the Australian Alps have declined from the 1950s, and projections suggest that the end of the snow season is likely to occur earlier in future, with a slightly later start, and lower maximum depths. These decreases in snow depth, cover and duration will be superimposed on large natural year-to-year variability (Hennessy et al., 2003). At ski resorts, seasonal variability in snow conditions can be managed to some extent through a range of practices such as snow-making, snow-grooming and snow-farming. The scope for adaptation through snow-making may need to be revisited to allow for recent and projected improvements in the technology (Bhend et al., 2012).

Climate change may favour some jellyfish species by increasing the availability of sources of jellyfish food. Warmer oceans could also extend the distribution of many jellyfish species. Open-ocean ecosystems can flip from being dominated by fish, to being dominated by jellyfish (Richardson et al., 2009). This could potentially impact tourism in areas impacted by increasing jellyfish numbers.

As described in section (d) above, coral reefs, salt marshes, mangroves and other natural coastal defence systems are at risk due to changing climate. Climate change is also likely to influence tourism through increased coastal storms, sea surge, and sea-level rise deteriorating beaches and increasing the need for beach protection and nourishment, and a warming ocean and ocean acidification would be detrimental to tourism at the Great Barrier Reef (Sustainable Tourism CRC, 2008).

An area for future research is to understand potential responses to these types of problems driven by major ecosystem changes.

l. Impact on financing and insurance arrangements for housing, buildings and infrastructure

l1. Current and future impacts of changes

Australia has increasing vulnerability to extreme weather events. From 1970-2013, insurance losses totalled $3b for fires, $5.4b for cyclones, $5.2b for floods, $6.3b for hail and $7.9b for storms (Productivity Commission, 2016). These figures omit uninsured costs and indirect costs. For example, high sea surface temperatures have repeatedly bleached coral reefs in north-eastern Australia since the late 1970s and more recently in western Australia; floods and cyclones have caused severe damage to infrastructure as well as many deaths and injuries; the Victorian heat wave of Jan-Feb 2009 led to black-outs and 374 premature deaths; bushfires in Feb 2009 destroyed more than 2000 buildings and led to 173 deaths; and widespread drought from 1997-2009 caused significant economic, social and environmental stress.

CSIRO has explored the current and future risks to residential housing from four hazards – coastal inundation, extreme winds, bushfire, and inland flooding (CSIRO, 2014). The study showed:

- For residential housing (worth around $5 trillion), the present value of expected direct damages in the absence of mitigation are substantial.
- At least half of these direct damages can be avoided through proactive intervention, applying well-known measures, and the cost of intervention is one-tenth or less than the damages avoided in present value terms.
- Most benefits occur in a limited number of places, enabling highly targeted interventions that are likely to have much higher returns on investment than the Australian average.
- In most cases, the benefit is immediate; that is, residential housing is significantly under-adapted to current conditions, so that mitigation investment has ‘no regrets’ benefits as well as greatly protecting against future change.
- The analysis is conservative in its assessment of benefits relative to costs, and includes neither indirect costs nor much other infrastructure entrained by housing.

If financing arrangements for these (mostly privately-owned) assets do not take account of the need to act on the growing climate risks, then the residual risk will be with uninsurable property owners and, the event of disasters, governments as ‘insurers of last resort’ and as recipients of fiscal risks through disruptions to the economy (as seen in the 2012 Queensland floods and other recent major events). In particular, as Public-Private Partnerships become more common, there is a tendency for the private part of the risk to play out in the near-term, with these initiatives transferring longer-term risks to non-partners and the public interest (Taylor and Harman, 2016). New approaches may be needed to manage public risk exposure.

m. The adequacy of current state and Commonwealth policies to assess, plan and implement adaptation plans and improved resilience of infrastructure

Australia needs a strong foundation in policies, laws, institutions and investments in research and technology to further reduce greenhouse gas emissions and adapt to build the resilience of communities, the economy and the environment (Australian Climate Change Science Programme, 2016). Planning needs to be adaptive, and incorporate no-regrets options, to account for the fact that Australia’s climate is changing. There is an ongoing need for sector- and region-based support and training in adapting to the inevitable impacts of climate change.

Indeed, adaptation depends more fundamentally on actions to change planning processes and policy, rather than ever more detailed information and analyses of impacts. New types of information involving multiple agencies, and new incentives to move away from current approaches, are required, along with an evolution of interacting values, rules and knowledge across the system (Gorddard, 2016). Such action can commence well before detailed impacts information is available. Adaptation does not need to involve immediate, massive changes in strategy and planning processes, but rather a gradual evolution of them (Wise et al., 2014).

Work also needs to be done to make research more accessible, to relate projections information directly to decisions and bridge the gap between science and policy- and decision-making. This includes tailoring information for regions and sectors, and also assisting non-experts to bring climate risk information into their normal decision-making workflows easily and authoritatively. For example, CSIRO has been working with the Department of Environment and Energy to develop the Climate Risk Information and Services Platform (CRISP) approach. This early prototype deliberately aims to supports business-as-usual workflows in decision-making by Commonwealth agencies.

Given Australia's commitment to the Paris Agreement (Paris Agreement Article 7) and launch of Australia's National Climate Resilience and Adaptation Strategy (Commonwealth of Australia, 2015), there may be potential opportunities to obtain synergies between mitigation and adaptation actions (Shaw et al., 2014; Spencer et al., 2017), especially in the land sector (Chandra et al., 2016; Duguma et al., 2014; Stokes and Howden, 2010; Thornton and Herrero, 2014) and built environment (Demuzere et al., 2014; Dulal, 2017; Kabisch et al., 2016). Failure to consider such interactions may risk undermining the effectiveness of mitigation interventions. For example, buildings may be built to good emissions standards, but an energy efficient office built in an inundation zone may end up causing more emissions through extra repairs and maintenance than are saved in energy efficiency. Thus, all other things being equal, mitigation options could be chosen which also enhance resilience to climate risks, now and in the future; this will likely enable the joint benefits to be achieved more cost effectively than otherwise.

Adaptation planning and implementation has been largely thematic, sectoral in nature or industry-based (Park et al., 2011). Taking such a narrow perspective potentially overlooks many complex economic, social and ecological issues and interactions, and may lead to unintended and maladaptive consequences. One powerful and unifying option could be to require that any public investment in infrastructure (or in planning processes that will influence infrastructure investments) that exceed some threshold value (e.g. $100m) should demonstrate that it has taken explicit account of potential climate risks over at least the asset lifetime. This type of approach could control what may otherwise be a rapidly increasing public and fiscal exposure to changing climate risks. Additionally, tools for integrated assessments of greenhouse gas emissions may help decision makers with policy implementation and new infrastructure developments, from individual dwellings up to the scale of major developments.

n. Other related matters

CSIRO has identified a range of gaps in approaches to adaptation to which research and development could contribute and help address:

1. Improving our ability to undertake an integrated assessment of current or proposed greenhouse footprints of a new developments, in terms of materials and ongoing use, is likely to help inform the evidence base of policies and decisions related to the contribution of greenhouse gases by new developments. Tools and models will be required to evaluate the impact of local, regional, national,

and global decisions on greenhouse gas emissions. Ideally this would be integrated with the impact of designs on adaptation effectiveness.

2. More robust research to underpin assessment of costs and benefits of adaptation may help inform financing and insurance arrangements, in particular to provide consistent access to an aggregated dataset for cost-benefit analyses as noted in section (e). Furthermore, further work may be required to inform investment decisions about climate change adaptation activities in order to take account of co-benefits such as to business as well as human health, the environment, etc.

3. CSIRO's fine scale work on impacts of climate change on housing provides information about the distribution of risks across a community. However, such considerations of the distribution of 'winners/losers' across broad regions tend not to be incorporated into analyses or decision making. If a government is going to pay for adaptation, everyone is subsidising those at risk, which may be fair and the most effective solution at, say, a suburb level, but in other places it may be more effective to work directly just with the 1 or 2 per cent of the population at risk. Further analyses of these distributional (horizontal and vertical) outcomes is needed (that is, broadening the approach of Fletcher et al., 2016 mentioned in j2).

4. Despite knowledge that the future will be different to the past, infrastructure planning and adaptation strategies are typically based on historical activities rather than future information. Projections of key metrics are required beyond those available, suited to decision making information needs. For example, in the water domain, decision-makers could potentially benefit from projections not just about changes to average volumes and seasonality of runoff and streamflow, but also of low-flow conditions and connectivity that impact water dependent ecosystems, overbank flow and floodplain inundation during high-flow conditions, and groundwater recharge. Similarly, further research could help to increase confidence in projections of heatwaves and runs of extreme hot days, particularly for the electricity sector. The ability to project changes in annual weather, such as runs of hot days and probabilities of more extreme hot days, at specific locations at the timescales required for electricity planning remains limited. (AEMO, 2013). All the ways that the electricity system may be affected by climate change need to be more fully determined (CSIRO, 2013).

5. In general, there may be benefits from closer connections between projections and policy implementation relating to infrastructure. Rather than generic projections, information about climate risks, their potentials impacts, and possible response options (with their costs and benefits) needs to be communicated in a way that directly relates to decisions for specific sectors and framed relative to policy, to bridge gaps between science and policy.

6. Much more needs to be done to take a whole-of-system view of adaptation, where the impacts of adaptation are considered and a holistic approach is taken to consider interconnectivity between sectors, scales, and feedbacks (for example, increasing use of water tanks may lead to increased mosquito-borne disease if interactions are not considered as part of policy implementation). This includes ensuring adaptation occurs in the context of changes beyond climate change.

7. Australia would likely benefit from a consistent set of national and regional scenarios that couple future climate with economic development and demography that are broadly accepted as the standards against which to plan for both public and private sectors.

8. In addition to a need for improved climate scenarios, there is also insufficient observational data and satellite data nationwide for complex modelling in an urban context – more consistency in data and more effective connections between data providers and data users are required.

Summary

By focusing on individual elements of infrastructure and the locations in which the direct effects of climate change occur (such as the coastline), considering the terms of reference above in isolation tends to draw attention away from two key ways in which climate change will affect infrastructure, and hence the functionality of our built environments: (i) the interdependent aspects of infrastructure that systemically deliver services to people and support to the Australian economy; and (ii) the secondary effects of climate change and the close relationship between mitigation of greenhouse gases and adapting to climate change through infrastructure. CSIRO suggests that for Australia to become well prepared for climate change effects on infrastructure that considerable attention is paid to understanding the systemic nature of interdependencies between elements of the infrastructure system, and the equally important interdependencies among the different decision making and implementing agencies responsible for infrastructure.

While direct effects of climate are substantial and likely to be expensive to the economy if not managed, the indirect effects that occur as a result of the responses to the primary effects are also large. For example, a current response for houses that are not fit-for-purpose for the temperatures experienced, is to use additional energy to cool the internal environment thereby having effects on power generation and power grids. With rising temperatures, existing housing stock will likely increase this problem and at the same time there is an opportunity to make sure all new housing stock is built to only need low energy inputs for heating and cooling. In this example housing standards appropriate for future conditions could achieve mitigation of emissions, adaptation to future living conditions and other indirect benefits to health and wellbeing. Other examples of these systems linkages can be identified when looking across the terms of reference. CSIRO urges that the committee consider the system of infrastructure co-dependencies and complex interactions of indirect effects, mitigation and adaptation.

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Additional information

CSIRO's past and present climate adaptation research: https://research.csiro.au/climate

CSIRO's Principles of adaptation decision making: https://research.csiro.au/eap

CSIRO Sea-level rise: Understanding the past – improving projections for the future. http://www.cmar.csiro.au/sealevel/index.html

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