Overview

Climate change and Australia

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Australia has had a variable and mostly arid climate as long as humans have been on the continent. Historically observed trends toward increased warming, with rainfall increases in many tropical areas and rainfall decreases in many temperate areas, are projected to continue. Impacts will be geographically variable but mostly negative for biodiversity, agriculture, and infrastructure. Extreme events such as bushfires and floods will increase in frequency and intensity, concentrated in summer. With an economy heavily dependent on coal for domestic electricity generation and as an export commodity, Australians are high per capita contributors to anthropogenic climate change. A quarter-century of steps to mitigation led in 2012 to a carbon price that has the long-term potential to shift the economy toward more renewable energy sources. However as in other parts of the world this change has come too late, and is proceeding too slowly, to avoid significant climate change. A heritage of indigenous adaptation, strong volunteer cultures, and contemporary cultural diversity provide Australia with considerable adaptive capacity for gradual changes, but the nation is underprepared for sudden or step changes. We identify four pressing research and policy needs focused on such changes: (1) systematic attention to processes and impacts of negative transformative change, or worst-case scenarios, (2) improve forecasts of year-to-year rainfall and climate variability, focusing on processes and climate drivers that may change in response to higher greenhouse gases, (3) identification and engagement of diverse cross-cultural resources, and (4) articulation of alternative governance mechanisms that can interact dynamically with strong government.

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INTRODUCTION

The Australian continent encompasses tropical, temperate, arid, and alpine habitats and climate regimes, all with high variability. The Australian nation faces climate change with high levels of affluence, consumption levels, and emissions growth.[1] Much of the continent is arid and fire-prone, with low soil fertility and low relief. Agriculture occurs in the more fertile and well-watered areas, with rangeland grazing spread across much of central and northern Australia. Both these land uses were introduced with European settlement in 1788, and both have contributed significantly to underlying environmental problems with which climate change is interacting—biodiversity decline, over-allocation and reduced quality of freshwater, localized salination.[2,3] With a long coastline and extensive maritime zones, the nation must also deal with the coastal and marine dimensions of climate change. Over 80% of people live within 50 km of the coast,[4] and all the major cities are coastal. Populations in rural and remote Australia bear disproportionate stewardship responsibilities for landscapes fundamental to food production and to the protection of plants, animals, soil, and water. For example, indigenous groups now own or control 23% of the land area of the continent.[5]

These factors combine to make the expression and impact of climate change in Australia

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geographically and socioeconomically variable. Climate processes interact in complex ways with other biophysical phenomena and social processes at varied temporal and spatial scales. In this paper we provide an overview of climate change trends, and set them in their political, economic, and sociocultural contexts. We outline steps taken in mitigation and adaptation, provide an overview of projected impacts, and identify contributions and gaps in research.

CLIMATIC BACKGROUND

At a geological scale, the aridity of the continent can be seen as a long-term consequence of its northward movement over the last 30 million years as part of the breakup of Gondwana. The final separation from Antarctica about 34 million years ago allowed the development of the circumpolar current, cutting off heat transfer from the equator[6] and leading to the development of the atmospheric circulation known as the Hadley cell. The interior of the continent is now arid to semiarid because it sits below the descending (drying) arm of this subtropical ridge. Periodically over the last 2 million years, the fluctuating 'glacial' climates of the Pleistocene took expression in these desert regions not so much in ice ages (as they did in the Australian alps) but as cold dry ages; the last glacial maximum was intensely arid as well as cold.[7] The north of the continent is now dominated by tropical climate systems; monsoonal rains during the summer wet season (November–April), with a dry season for the remainder of the year. Further south the climate is characterized by winter storm activity originating in the Southern Ocean, and summer high pressure systems pushed southward by the monsoon.

Superimposed on this general structure is high year-to-year rainfall variability. Overall Australian rainfall patterns are heterogeneous regionally and seasonally. Rainfall from tropical cyclones can penetrate well into the continental interior causing intermittent widespread inundation. The El Niño-Southern Oscillation (ENSO), a tropical Pacific Ocean change in ocean heat content and atmospheric circulation, occurs intermittently every 2–7 years and significantly affects interannual rainfall patterns in eastern and southern regions. El Niño events are associated with increased likelihood of drought, and La Niña events with above average rainfall. Sea surface temperatures across the Indian Ocean (the Indian Ocean Dipole) and the position of the Southern Hemisphere westerlies (the Southern Annular Mode) also play a role in rainfall variability, particularly in the south of the continent. These climatic processes, that operate from geological to decadal and shorter timescales, severely constrain water availability and have had major impacts on past and present populations.

HISTORICAL CONTEXT OF A FOSSIL FUEL ECONOMY

The first people arrived in Australia about 50,000 years ago, when the interior was cooler and wetter than today. There have been arguments that subsequent Aboriginal burning practices helped contribute to a drying climate,[8] nevertheless Aboriginal groups are widely seen as having adapted successfully to fluctuating Pleistocene conditions, including the much harsher climates of the last glacial maximum, and also to the warmer, wetter, and more diverse environments of the Holocene (the last 10,000 years).[7,9] With colonization by the British at the end of the 18th century, an economy in the throes of the industrial revolution—with concomitant demands for resources—was brutally superimposed on a hunter-gatherer landscape. Australia's contemporary economy was built on this history of exporting primary products and raw materials. Key 19th century exports, gold and wool, have now been overtaken by coal and iron ore, but the legacy of the quarry and the farm continues to shape emissions patterns.

In 2005, Australia ranked 15th in the world as a producer of greenhouse gas emissions, contributing 560.0 million metric tonnes of CO_2 equivalent (1.48% of total).[10] Australia's per capita emissions (28.1 tonnes of CO_2 equivalent, 2006 data) are the highest of any OECD country, nearly twice the OECD average and more than four times the world average.[11]

Australia's per capita emissions are high because electricity production (35.8% of national emissions, 2010–2011 data) is dominated by the burning of coal.[12] Transport (16.1%) and agriculture (14.5%) are also significant contributors (Table 1). Black and brown coal account for the greatest share of the energy mix (37%), followed by petroleum products (35%) and gas (23%) (Figure 1). Renewable energy has remained largely constant at around 5% of the energy mix over the last decade. Of this, around 67% is sourced from biomass (wood and bagasse), 16% from hydro-power, and 17% from biofuels, wind, and solar energy.[13] Nuclear energy is not used, and there is considerable potential for geothermal energy.[6]

Australia also contributes to global emissions via the fossil fuels it exports. In 2007–2008 Australia exported (as coal, uranium, and gas) more than two thirds of the geologically stored energy that it extracted.[14] The country is the world's largest coal exporter.[15]

TABLE 1 | Australian Greenhouse Gas Emissions by Sector, 2010–2011.[12]

Sector	Emissions (Mt)	Per cent
Electricity	193.0	35.75
Stationary energy (excluding electricity)	97.3	18.03
Transport	86.8	16.08
Fugitive emissions	37.5	6.95
Industrial processes	32.9	6.09
Agriculture	78.2	14.49
Waste	14.2	2.63
Total	539.8	100.00

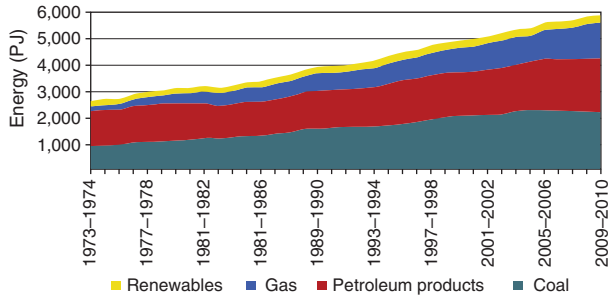

FIGURE 1 | Australia's total primary energy supply, by energy type, 1973–2010.[13]

TABLE 2 | Australian Energy Consumption by Sector and Industry, 2009–2010.

Sector	Consumption (PJ)	Per cent
Manufacturing	1034	26.08
Households	1015	25.61
Transport, postal, and warehousing	544	13.72
Mining	543	13.70
Other services	429	10.82
Electricity, gas, water, and waste services	146	3.68
Construction	144	3.63
Agriculture, forestry, and fishing	109	2.75
Total	3964	100.00

Source: Ref.[16]

Energy consumption is dominated by the electricity generation, transport, and manufacturing sectors. In 2009–2010 industry accounted for approximately three-quarters of the energy used, with households accounting for the other quarter.[16] Of all sectors, the manufacturing industry was the largest end user of energy by industry (Table 2).

CLIMATE CHANGE—OVERVIEW OF TRENDS

This fossil fuel-based economy, repeated in different forms in many parts of the world over the 20th century, and particularly since 1950[17], has contributed to the climate changes already being experienced in Australia and around the world.[18] In this section we outline historical and projected trends in Australia.

Temperature Trends

From 1910 to 2011 the Australian continent has warmed 0.9°C,[19] more than the global average of 0.7°C for the same interval.[20] Furthermore, the majority of this warming has occurred since 1950, with every decade after 1950 being warmer on average than that preceding.[18] At the regional scale there are significant heterogeneities, with the east recording up to 2°C increase since 1960 and the northwest recording a slight cooling (−0.4°C). Climate model simulations reproduce Australia's temperature trends when the simulations include greenhouse gas forcing, in addition to natural climate forcing factors (e.g., solar and volcanic).[21,22]

The continent-scale trends observed recently are projected to continue into the future as atmospheric greenhouse gas concentrations increase, though the trend is likely to be amplified as land areas warm faster than oceans.[23] Although it is important to identify the long-term trends, on a shorter timescale there is also evidence that anthropogenic warming has occurred in discrete steps rather than gradually,[24] with significant implications for adaptation.

Rainfall Trends

As the driest inhabited continent on Earth, Australia is particularly vulnerable to relatively small changes in rainfall. Four regions have experienced significant changes in rainfall since 1900 and particularly since 1950[25]: northwest Australia, southwest Western Australia, southeast Australia, and northeast Australia (Figure 2).

The northwest is the only region to have experienced a long-term increase in annual rainfall, predominantly in the summer months.[20,26] This change is attributed to higher atmospheric levels of aerosols, particularly from Asia, enhancing cloud formation and rainfall,[27,28] and to changes in the monsoon trough leading to more intense atmospheric convection.[26]

Southwest Western Australia has recorded a steady decline in rainfall over the past 30 years, with a 15% decrease in winter rainfall since the

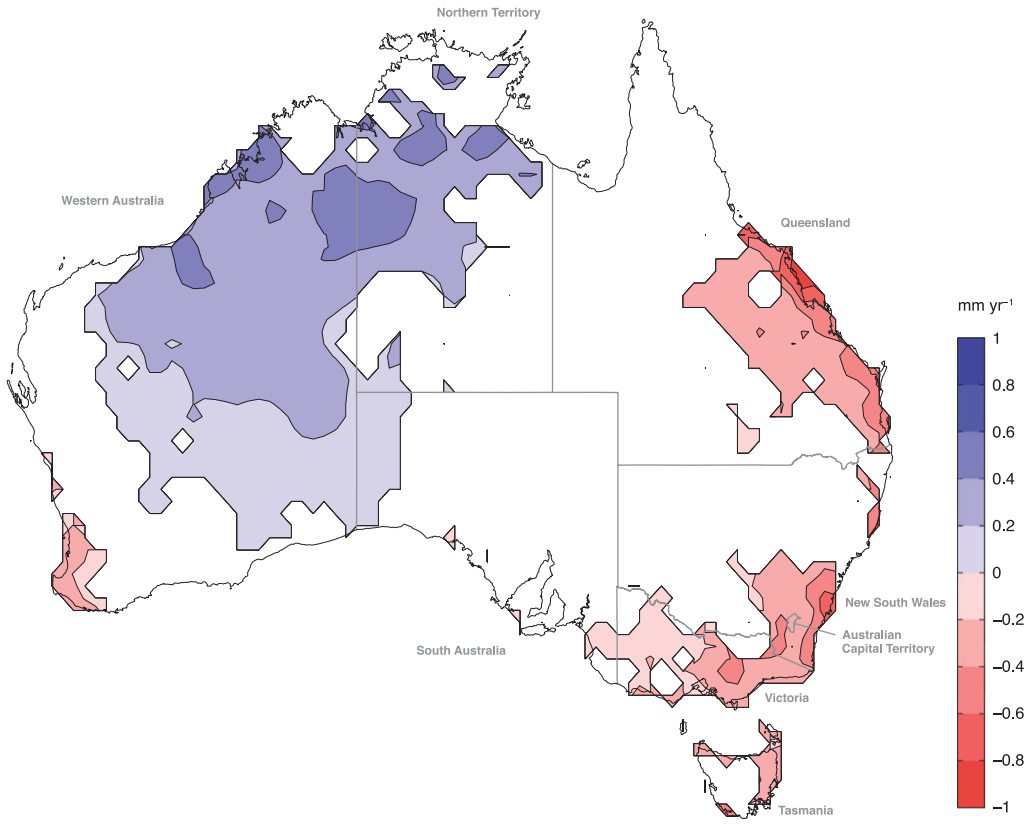

FIGURE 2 | Trend in rainfall based on 1950–2007 period (mm year^{-1}).[23]

mid-1970s.[20] The decline is associated with a southward displacement of storm tracks,[29] changes in greenhouse gases and ozone,[30] and/or landuse changes.[31] The rainfall decline in southwest Western Australia has resulted in a 60% reduction in stream flows, with implications for water storage for Perth, the West Australian state capital.[20,23]

The southeast and east of Australia have experienced drying since the mid-1990s (see Box 1), including a 61% decrease in March–May rainfall.[32] There are likely multiple causes for the decline. Rainfall variability in eastern Australia is closely associated with the ENSO, in combination with other factors.[23] However, the frequency and intensity of El Niño events have increased since the 1970s; ENSO displays large year-to-year variability and so far it has not been possible to characterize the true nature of this variability and any links to global warming.[33]

Rainfall and Temperature Extremes

Changes in Australian rainfall trends are dominated by changes in very heavy rainfall events, that is, there has been a decrease in very heavy rainfall events in eastern Australia and an increase in western Australia.[26] Trends in extreme rainfall are not only strongly correlated with average rainfall trends but also positively associated with average temperature and extreme temperature trends.[40] In terms of extreme temperatures, the number of record-breaking hot days per decade has increased every decade since the 1950s,[20,41] pointing to an increased frequency of warmer weather (Figure 3).[40] Combining temperature and precipitation extremes into a single index shows that from 1911 to 2008 hot/wet extremes have increased in all seasons at an average rate of 1–2% per decade.[18] Australia is likely to experience warmer temperature extremes with increased warm nights and heatwaves, and longer dry spells with intermittent extreme precipitation.[42]

Extreme Events

Although no single event can be attributed directly to anthropogenic climate change, extreme events are projected to occur more frequently as warming continues. Further, long-term and regular processes such as droughts are displaying different characteristics. The 'Big Dry' of 1995–2009 (also referred to as the Millennium Drought) (see Box 1) is one such example, displaying meteorological characteristics[43] that are different from earlier

BOX 1

THE 'BIG DRY'—SEVERE DROUGHT 1995–2009

The period from 1995 to 2009 is referred to as the 'Big Dry'[34] or Millennium Drought, during which the southeast of Australia (east of 135°E and south of 33°S) experienced the most severe drought of the past 120 years of instrumental records.[35] On the basis of palaeoclimatic reconstructions it is likely that the decade 1998–2008 was the driest since European settlement.[36] The Big Dry was characterized by a decline in autumn and winter rainfall, and an absence of very wet years, and this autumn/winter rainfall deficit continues despite the exceptional wet years of 2011–2012. The Big Dry, along with the Federation Drought (1895–1902) and the World War II drought (1937–1945) are attributed to cooler conditions over the Indian Ocean that change wind fields such that moisture flux anomalies are directed away from Australia toward east Africa,[37] although changes in other synoptic rainfall patterns may also play a role.[32,38] The unprecedented severity of the Big Dry, however, was exacerbated by recent temperatures 0.3-0.6°C above the long-term average.[39] This period faced a number of tragic bushfire events, including the Canberra fires of January 2003 and the Victorian 'Black Saturday' fires of 2009.

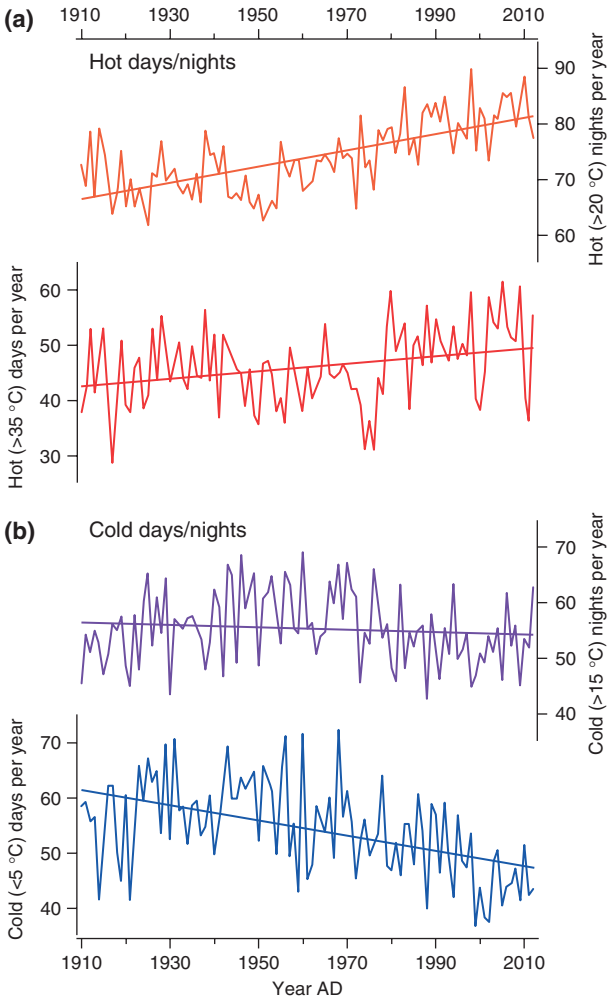

FIGURE 3 | Trends in Indices of extreme temperature for Australia, 1910–2012. (a) Annual count of hot days and nights. Hot days have maximum temperatures >35°C and hot nights have minimum temperatures >20°C. (b) Annual count of cold days and nights. Cold days have maximum temperatures <15°C and cold nights have minimum temperatures <5°C. (Data source: Bureau of Meteorology).

droughts; these appear to be related to global warming.[44] Austral summer (December-January-February) is the season when extreme events will likely be experienced most often because both tropical (cyclones, floods, coastal storms) and temperate (prolonged heatwaves, heat stress, fires) extremes occur at this time. This will create seasonal pressures on emergency services, an issue we discuss further below. The period 2009–2013 includes a number of extreme weather events, where their severity and impacts may be partial analogs for future extremes:

Heatwaves, Heat Deaths, and Bushfire Weather

Two of the most severe bushfires in recent times, the 'Black Saturday' (February 7, 2009) and the severe January 2013 bushfires across southeast Australia, occurred during record-breaking heatwaves.[25,45,46] The Black Saturday bushfires in the greater Melbourne metropolitan area occurred during the second of two exceptionally warm episodes during the prevailing heatwave: 6–8 February, when Melbourne recorded its highest ever maximum temperature (46.4°C on February 7, the day of the bushfires[46]). The 'Black Saturday' fires killed 173 people in the Melbourne metropolitan area.[25] The first week of the heatwave (January 26 to February 1) included the exceptionally warm 28–31 January interval, and Melbourne's highest average daily temperature was recorded (35.4°C on January 30). Worryingly, during this phase of the heatwave there were an additional 374 deaths in greater Melbourne compared to the long-term average for comparable periods in the past.[47]

The January 2013 bushfires in Tasmania, Victoria, and New South Wales also occurred during an interval when most of Australia experienced near record-breaking heat. The so-called 'Angry Summer'[48]

occurred following warmer than average temperatures for austral spring and early summer 2012.[45] During the prolonged and extensive heatwave, from late December 2012 through to mid-January 2013, most of Australia experienced extreme heat at some point, and as a result January 2013 is now Australia's hottest month on record.[45]

Bushfire risk depends on the dryness and amount of fuel, prevailing weather, and likelihood of ignition. Of 38 sites where fire weather trends from 1973 to 2010 were analyzed, 16 have experienced a significant increase in fire risk and none showed a significant decrease.[49] Climate forecasts suggest that heatwaves and bushfire weather are likely to occur more frequently in the future.

The Wettest 2-Year Period on Record—2010–2011 and the Floods of January 2013

The 'Big Dry' in southeast Australia ended in 2010, with heavy rain events heralding Australia's wettest 2-year period on record.[50] The heavy rainfall led to major river flooding in Queensland and New South Wales, including in the Queensland capital Brisbane. Most of the continent received rainfall very much above average, the exception being the southwest corner, which in 2010 had its driest year on record. The exceptional rainfall was strongly associated with back-to-back La Niña events and with the highest sea surface temperatures in the region since 1900.[25] The La Niña of 2010–2011 was one of the strongest ever recorded and, although the La Niña event of 2011–2012 was weaker, it also coincided with warm ocean temperatures. While much of Australia experienced extreme heat in early to mid-January 2013, from 22 to 29 January heavy rainfall triggered severe flooding along coastal Queensland and northern New South Wales, comparable in magnitude to the flooding in 2011.[51] The relationship between heavy rainfall and warmer ocean and atmospheric temperatures is well established, and precipitation extremes are likely to occur more often in the future.[52]

Ocean Temperature and Sea Level Rise

Much of Australia's population reside along the coastal fringe and the effects of rising greenhouse gas concentrations are already being felt in marine environments. Ocean surface temperatures around Australia have increased by 0.9°C since 1900,[20] higher than the global average of 0.7°C, and the rate of warming has accelerated in recent decades.[53] Warming is greatest in the southeast and southwest of the continent.[20] The increased warmth has shifted coastal climate zones for 10.5–29.5°S south by >200 km along the east coast and 100 km along the west coast.[54] Significant coral bleaching has occurred on the Great Barrier Reef between 1998 and 2002.[20]

Systematic monitoring of sea levels around the Australian coastline began in the early 1990s. Although trends are difficult to confirm over such a short record, sea levels have risen around Australia, consistent with global trends.[55,56] Rates of sea level rise have been greatest on the western and northern coasts, and are linked to interannual climate variations (e.g., ENSO), changes in the strength of the East Australia current, and atmospheric circulation. Sea level rise has exacerbated the impact of storm surge events, which coincide with strong onshore winds and high tides, resulting in coastal flooding and erosion.[57] Sea levels are projected to continue to rise to 20–60 cm above 1990 levels, although this could be higher since considerable uncertainty surrounds the degree of ice sheet melting in response to global warming.[3]

From the above examples it can be seen that Australia is already experiencing the effects of climate change. This has taken place so far mostly via weather patterns, particularly extreme events, that are historically recognizable but will likely occur with greater frequency and/or intensity.

POLITICAL MOVES TOWARDS CLIMATE CHANGE MITIGATION

Within this context of changing climates, a carbon pricing scheme, or 'Carbon Tax', was brought into effect on July 1, 2012. This is no mean feat for the world's largest coal exporter, but it was a 'long and bruising'[58] political road. More than two decades of initiatives and several changes of government led up to this legislation (Table 3), eventually passed by a minority Labor government with the support of the Greens party and independents, and vociferously opposed by powerful mining and energy interests.[62] As Table 3 shows, there was more history of bipartisanship toward the end of the previous Howard government. By 2008 there was majority support (58%) for an Emissions Trading Scheme, with a significant minority (22%) opposing.[63] Opposition could include Greens supporters who thought the proposed Scheme to be ineffectual, as well as climate change sceptics or others who thought the scheme too strong. This bipartisanship disappeared completely once Malcolm Turnbull lost the Opposition leadership to Tony Abbott in 2009.[64]

The long period of political preparation meant that there was also a long period of bureaucratic

TABLE 3 | Australia's Labor Party is left-leaning and the Liberal Party is right-leaning.[59–61] *(Federal Elections in 2010, 2007, 2004, 2001, 1998, 1996, 1993)*

Date	Action
1987–1988	CSIRO and Commission for the Future convene major conferences and publish outcomes.
1989	State governments of NSW, Victoria, and WA adopt Toronto target (20% reduction in 1988 greenhouse gas levels by 2005) as interim objective.
	Hawke (Labor) signs Declaration of The Hague, which recognized the global significance of climate change
	Hawke Government does not sign up to Toronto target but establishes National Climate Change Program to assess achievable targets.
1990	Hawke Government adopts an interim planning target of stabilizing emissions at 1988 levels by 2000 and reducing by 20% by 2005. Caveat includes that 'the Government will not proceed with measures which have net adverse economic impacts nationally or on Australia's trade competitiveness in the absence of similar action by major greenhouse gas producing countries'.[59]
1992	Federal-State Council of Australian Governments endorses National Greenhouse Response Strategy.
	Keating (Labor) signs the United Nations Framework Convention on Climate Change (UNFCCC).
1995	Keating Government introduces Greenhouse 21C program and Greenhouse Challenge Program involving voluntary agreements with major industrial emitters.
	NSW Carr Labor Government implements Green Power Schemes and establishes Sustainable Energy Development Authority.
1997	Howard (Liberal) Government establishes Australian Greenhouse Office and announces Renewable Energy Policy (which originally required the electricity sector to source an additional 2% of electricity from new renewable sources).
1998	Australian Greenhouse Office releases the National Greenhouse Strategy, which acknowledges climate change and Australia's international obligation.
2000	Howard Government establishes the Photovoltaic Rebate Program (PVRP) which offered rebates to households and community groups to install PV power systems.
2006	Howard Government establishes the Prime Ministerial Task Group on Emissions Trading to advise on implementation of an emissions trading scheme (ETS).
2007	Howard Government commits to introducing an ETS.
	Rudd (Labor) Government ratifies Kyoto Protocol following November Federal election.
	Department of Climate Change established.
	Photovoltaic Rebate Program rebranded to Solar Homes and Communities Program (SHCP).
2008	White Paper released on Rudd Government's Carbon Pollution Reduction Scheme (CPRS).
	National Solar Schools Program in operation, offering schools competitive grants to install solar and renewable power systems, rainwater tanks and energy efficiency measures.
2009	CPRS legislation introduced into Parliament, voted down in the Senate twice.
	Solar Homes and Communities phased out and replaced by Solar Credits Program.
	Rudd Government introduces Home Insulation Program and the Solar Hot Water Rebate Program (replaced by Renewable Energy Bonus Scheme in 2010).
2010	Gillard (Labor) Government establishes the Multi-Party Climate Change Committee (MPCCC).
2011	MPCCC recommends a fixed carbon price be implemented 1 July 2012, transitioning to a flexible-price cap-and-trade ETS on 1 July 2015.
	Clean Energy Bill is introduced and passed by Parliament.
2012	Carbon price brought into effect on 1 July 2012.

preparation. Government-funded institutions such as the Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) have played an important role in building long-term data sets, modeling future changes, emissions scenarios, and energy alternatives, and communicating with the public. The recent politics of climate change have been particularly fraught, reflecting the dependence of the nation on fossil fuels and the difficulty of the task. There have been splits

between political parties, between environmental and energy ministers (and their departments) and within the Australian population (see following section). Climate change indirectly contributed to two recent opposition leaders (Nelson and Turnbull), three prime ministers (Howard, Rudd, and Gillard), and a number of senior ministers losing their jobs.

The carbon price, one part of a broader energy reform package called the Clean Energy Plan, aims to reduce greenhouse gas emissions in Australia by 5% below 2000 levels by 2020, and 80% below 2000 levels by 2050. Government will be advised on annual caps and future emissions targets by an independent, expertise-based body, the Climate Change Authority.[65] The scheme currently requires liable entities, characterized as 'Australia's largest polluters' (numbering about 323 as at January 2013), to buy permits for each tonne of CO_2 emitted. A fixed price was to apply for the first 3 years, after which the price would be set by the market (the government has recently brought forward the date of the change by 1 year).[66] Major industries affected by the carbon price include electricity and energy generators, mining, business transport, and waste and industrial processors. Incorporated into the scheme are financial assistance and energy efficiency measures for households and businesses. In the first 3 months of operation of the carbon price, hydro electricity generation increased and coal-fired generation decreased,[67] and this pattern had continued after 1 year.[68] The government figures indicate that renewables increased their proportion of electricity generation by 28.5% and coal decreased its by 17.5% over the first 12 months of operation.

Since its inception the carbon price has received mixed reviews from both the media and the public, often centring around the fact that Prime Minister Gillard had to break a promise to implement it. As the nation approaches an election in late 2013, the future of the carbon price is not clear at the time of writing. The Rudd Labor government has signaled an intention to move 1 year earlier than planned to an emissions trading scheme, with the price set by the market, and the Abbott Liberal opposition has promised to abandon the scheme entirely. As Jotzo argues, 'Australia's carbon pricing mechanism might enter history as one of the best-designed yet shortest-lived policies for climate change mitigation'.[58]

The task of shifting an economy away from its historical dependence on fossil fuels—not only for domestic consumption, but also as an important part of export industry—has a high degree of difficulty. Because of the scale required, and for consistency across the economy, only a strong national government can accomplish this task, albeit with cooperation and coordination between state and local governments. Even then any government will likely face mixed responses from the population, who may have to make some sacrifices.

CULTURAL PERSPECTIVES ON CLIMATE CHANGE

What Australians believe about climate change helps in understanding the political arguments.[69] Most Australians accept that climate change is happening (about 75%, depending on the wording of the question), but only about 50% think human activity is the main driver. However, about 90% agree that climate change is 'partially' human-induced. Consistent with trends in other Western countries, a decline in climate change belief since 2008 is evident (8–10% decline, depending on the poll). Suggested factors are the global financial crisis, the failure of Copenhagen and 'climategate' in December 2009,[70] but none of these have been systematically tested. Also consistent with the United States and Western European countries, higher levels of belief in human-induced climate change are found among women and people with left-wing political beliefs (including politicians themselves).[64,69,71] Reasons for these gender differences have not been fully researched, but are consistent with the 'white male' effect[72] in accepting higher levels of risk (e.g., in bushfire preparedness[73]). A less powerful predictor of belief in climate change is the rural/urban divide, with slightly but statistically significant lower levels in rural areas, and marked differences between city dwellers (58%) and primary producers (27%) in believing that human activity is the primary cause of climate change.[69] Although it is widely recognized that resilience and adaptive capacity are culturally variable, research is just beginning to pay attention to the role of ethnicity.[74,75]

Climate change denialism is strong in Australia, although there is a limited amount of academic research into its sources and expression. As in the United States, denialism is closely associated with conservative think tanks.[76] In one detailed study, five different sceptical discourses were identified among residents of the Australian Capital Territory.[77] These were 'closely intertwined with other beliefs such as mistrust of institutions and protectiveness toward Australia's national interests' (p. 408). In a rare anthropological analysis[78] in the Hunter Valley region of NSW (an important coal mining area), Connor argues that climate change has set in train a cultural crisis. She argues that discourses of fear, scepticism,

denial, and apathy gain traction because 'in Australia today, the dominant symbolic systems, religious or secular, do not contest the life-affirming messages of fossil-fuel fired consumer culture'.[78]

Opinions vary in Australia over how much power denialist arguments actually wield with both politicians and the broader public. While there are some deeply entrenched cultural factors that are important to understand, it would be a mistake for researchers to focus only on denialism. Even those who accept the science on climate change have trouble imagining the scale of mooted and/or necessary socioeconomic transformations, whether chosen or forced. One role for researchers is to help imagine how different scenarios may play out in practice. Further, while public education programs are important,[79] cultural perspectives on climate change are much broader than just questions of attitude and belief. Among farmers, for example, adaptive capacity does not map neatly onto climate change belief, but relates to a combination of social and economic factors influencing resilience.[80] Beliefs interact with everyday practice and socioeconomic structures in complex ways that we consider below.

IMPACTS AND MOVES TOWARDS ADAPTATION

Projected climate changes are likely to have significant impacts on Australia's infrastructure, agriculture, fisheries, and unique flora and fauna (Table 4). There are likely to be positive feedbacks between different influences, e.g., increased bushfire risk and frequency[81] will influence biodiversity outcomes. There has been increasing recognition that 'already Australia faces a stark fact—the opportunity to avoid climate change altogether has passed'.[82] A growing body of research now focuses on how to *adapt*[83] to extreme events and bushfires,[84–86] drier conditions,[87] rising sea levels,[88,89] and heat-related effects including reduced life expectancy.[90]

The Federal Government funded a National Climate Change Adaptation Research Facility (NCCARF) 2008–2013 to coordinate blueprints for research across a 5–7 year time horizon. Nine themes were selected: Terrestrial Biodiversity, Marine Biodiversity and Resources, Human Health, Freshwater Biodiversity, Settlements and Infrastructure, Emergency Management, Primary Industries, Indigenous Communities, and Social, Economic, and Institutional Dimensions. Adaptation Research Plans were produced under each theme, and a program of grants funded initial research (see www.nccarf.edu.au for full list of plans, publications, and policy guidance briefs).

Among the last publications produced by NCCARF before funding ceased on June 30, 2013 were synthesis reports for each state. To take the New South Wales synthesis report as an example,[91] there is a combination of quite specific recommendations with much more general ones. Specific recommendations include the need for a heatwave policy in aged-care facilities, while more general ones include that agricultural adaptation will be primarily driven in the private sector, with government playing a supporting role. A further issue is that while the key recommendations for state government decision makers in the same report are very general, some would be extremely radical if implemented properly; for example, the need to 'ensure structures and institutions are flexible and can react to emerging issues and unforeseen events'.[91]

The evidence indicates that Australia is still in the early stages of considering climate change adaptation and its relationship to other aspects of public policy. A survey of government and business organizations in late 2008[92] found that: 'only 59% of surveyed organizations have conducted a formal vulnerability assessment, and less than 40% have implemented any specific planning or other changes aimed at adapting to future climate change impacts'. Adaptation activity was found to be linked to knowledge and beliefs about climate change issues, and is stronger in organizations with longer planning horizons. Adaptation actions that can be implemented by Australian governments are linked to their functions, including—for local government as an example—infrastructure and property services, planning and development regulation, provision of health, water and sewage services, and natural resource management.[93,94] However, as a survey of coastal councils in five states shows[95] (Figure 4), most are still in a state of risk analysis and strategy preparation.

It is of course difficult to separate adaptation to climate change from adaptation to other drivers of change and uncertainty that might apply, whether in business, agriculture or natural resource management. And this need not be a problem. As Dovers argued,[96] incremental climate change can be well adapted to using existing social and economic systems that may well already be effective even if they have nothing to do with climate change. With strong civic institutions and a robust volunteer culture (more than one third of the adult population did voluntary work in 2010[97]), Australia has a long heritage of coping stoically with the management of emergencies such

TABLE 4 | Differences between Probable Unmitigated and Mitigated Futures at 2100—Median of Probability Distributions

Sector	No mitigation	Mitigation 550 ppm CO_2-e	Mitigation 450 ppm CO_2-e
Irrigated agriculture in the Murray-Darling Basin	Ninety-two percent decline in irrigated agricultural production in the Basin, affecting dairy, fruit, vegetables and grains.	Twenty percent decline in irrigated agricultural production in the Basin.	Six percent decline in irrigated agricultural production in the Basin.
Natural resource-based tourism (Great Barrier Reef and Alpine areas)	Catastrophic destruction of the Great Barrier Reef. Reef no longer dominated by corals.	Disappearance of reef as we know it, with high impact to reef-based tourism. Three-dimensional structure of the corals largely gone and system dominated by fleshy seaweed and soft corals.	Mass bleaching of the coral reef twice as common as today.
	Snow-based tourism in Australia is likely to have disappeared. Alpine flora and fauna highly vulnerable because of retreat of snowline.	Moderate increase in artificial snowmaking.	
Water supply infrastructure	Up to 34% increase in the cost of supplying urban water, due largely to extensive supplementation of urban water systems with alternative water sources.	Up to 5% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources.	Up to 4% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources.
Buildings in coastal settlements	Significant risk to coastal buildings from storm events and sea-level rise, leading to localized coastal and flash flooding and extreme wind damage.	Significantly less storm energy in the climate system and in turn reduced risk to coastal buildings from storm damage.	Substantially less storm energy in the climate system and in turn greatly reduced risk to coastal buildings from storm damage.
Temperature-related death	Over 4000 additional heat-related deaths in Queensland each year. A 'bad-end story' (10% chance) would lead to more than 9500 additional heat-related deaths in Queensland each year.	Fewer than 80 additional heat-related deaths in Queensland each year.	Fewer deaths in Queensland than at present because of slight warming leading to decline in cold-related deaths.
Geopolitical stability in the Asia-Pacific region	Sea-level rise beginning to cause major dislocation in coastal megacities of south Asia, south-east Asia, and China, and displacement of people in islands adjacent to Australia.	Substantially lower sea-level rise anticipated and in turn greatly reduced risk to low-lying populations. Displacement of people in small island countries of South Pacific.	

The assessment of impacts in this table does not build in centrally coordinated adaption. The median of the probability distribution is used for the scenarios considered.[11]

as fires, cyclones, and floods. However increases in the frequency and intensity of such hazards will create new pressures and vulnerabilities. For example, following repeated Queensland floods, some insurance companies have increased premiums and become less willing to insure houses on floodplains.[98] A recent report on preparedness for extreme events concluded that there is considerable variability in preparedness across organizations and different sectors of society.[99] Developing effective coordination between different levels of government, including the need for interoperability of emergency service organizations and their key personnel, were identified as important issues.

There are also major questions over whether a gradualist conceptualization of climate change leads to only incremental adaptive responses, leaving the community poorly equipped for unanticipated rapid

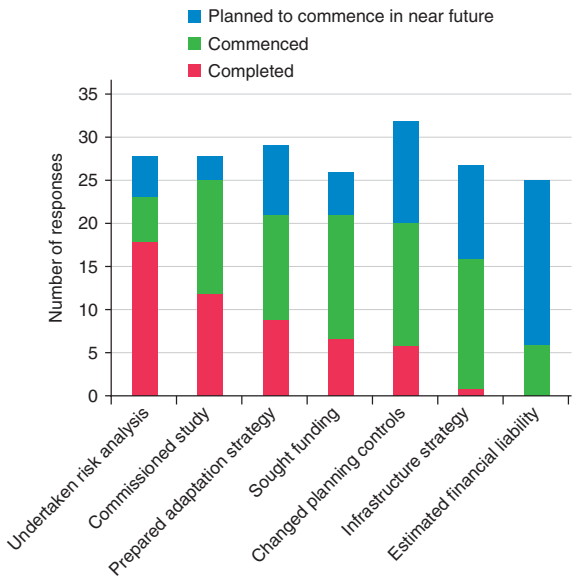

FIGURE 4 | Initiatives undertaken or planned by coastal councils. $N = 34$.[95]

or severe change.[24,100] For example, an NCCARF overview argues that 'whilst there is a large body of research to assist the emergency management sector to adapt to the current climate, research that considers future conditions is not as well developed'.[101]

Biodiversity

Climate change clearly alters biodiversity and interacts with the processes (such as land use change) that have caused many extinctions over the last 200 years.[102] Both native and exotic 'ecologically generalist' species are likely to expand their range at the expense of native specialists, and extinction rates of narrow-ranged endemics, especially in montane and coastal habitats, will increase.[102] For example, of 100 *Banksia* species in the global biodiversity hotspot of southwest Western Australia, two thirds are projected to decline in range and only 6% to expand or remain stable. Between 5 and 25% would suffer range losses of 100% by 2080, primarily because of precipitation decline.[103] As we move into what are referred to as no-analog conditions, species will combine in new and unpredictable ways, known as novel ecosystems.[104]

Coral-based ecosystems, including the World Heritage Great Barrier Reef, are among the most vulnerable. Between 1998 and 2003 coral bleaching occurred on 50% of reefs within the GBR Marine Park, the most severe since first records of this process in 1979.[105,106] Bleaching occurs when ocean temperatures rise to 1–2°C above the long-term summer maximum and are sustained for several weeks. If global temperatures rise by 2°C by 2100, bleaching is forecast to occur annually and would likely result in a shift to macro-algae dominated communities by 2050. Other impacts on coral reefs include ocean acidification, increased susceptibility to disease, damage from tropical cyclones and storm surges, changes in community structure due to sea level rise, and the growth of reefs at higher latitudes.[3,107]

Additional likely marine impacts include expansion of mangroves as coastal lands flood, damage to sea grass meadows due to the increased storm frequency, and changes due to ocean acidification.[4] Heatwaves occur in oceans as well as on land. In the summer of 2010–2011 a warming anomaly 2–4°C persisted for more than 10 weeks in the Indian Ocean along the coast of southwestern Australia, where the tropical/temperate transition zone is a hotspot of marine biodiversity. The event led to a significant shift in the community structure, suggesting that it is these extreme events that dominate marine ecosystem structural change.[108,109]

The combination of climate and biodiversity changes will challenge the national reserve system in several ways. Reserve systems based on static distributions, or framings of restoration as a return to historical baselines, will be inadequate for the changes already in train. Enhanced connectivity between separate reserves, and increased integration with off-reserve lands, will be needed to allow species to move, where possible.[110] The recently announced National Wildlife Corridors Plan attempts to address these issues by promoting a 'whole-of-landscape' approach integrating multiple land uses including biodiversity conservation. It is too early to assess the effectiveness of this plan, and some farmers' organizations have raised equity questions about the policy mechanisms.[111,112] All recent increases in protected areas have been on private [e.g., through environmental non-governmental organizations (NGOs)] or Aboriginal land, or via partnerships between them.[113] Some of these are very substantial, with Indigenous Protected Areas contributing nearly a third of the National Reserve System, and likely to contribute to connectivity objectives.[114] However, the expectation that species will simply shift poleward or upward is too simplistic; more multidirectional movements have been demonstrated historically for 464 Australian bird species.[115]

Agriculture

Agriculture in Australia has long had to cope with climatic variability at a range of timescales, and this increases farmer confidence that they are reasonably

well equipped for gradual change.[80] The projected climate change impacts on agriculture vary across the continent (Tables 4 and 5).[116–118] Changes in extremes (e.g., higher peak temperatures and fewer frosts) will have more impact than changes in average temperature,[119] and rainfall changes will affect crops more than livestock. Water is the biggest issue; in the southeast and southwest of Australia today, water resources are fully or overallocated, even in years of average rainfall,[120] but the north of the continent will get wetter. Earlier wine-grape ripening has been identified due both to warming and declines in soil moisture.[121]

Irrigated agriculture in the Murray-Darling Basin is most at risk, particularly in the absence of mitigation. High levels of water extraction for irrigation are calculated to be a greater threat to ecosystem health in the Murray-Darling Basin than climate change, emphasizing the importance of systems of water governance.[118,122,123] Centralization of basin management through the 2007 Water Act, combined with voluntary sales of water rights by irrigators during the Big Dry (Box 1), has delivered some environmental benefits. These are difficult to measure on conventional economic analyses, compared with agriculture, for example, but CSIRO estimate that they are considerable, including the gains made in carbon sequestration by maintaining large areas of river red gum and black box floodplain vegetation.[124] Such gains are arguably easier to achieve during a crisis, and some argue that political momentum has been lost since the end of the drought.[122]

To take the example of wheat, productivity projections at 2030 are regionally variable, and include predictions of both decreased and increased productivity under different rainfall scenarios,[125] with considerable uncertainty about how enhanced CO_2 will interact with rainfall and temperature.[126] Rainfall decreases are projected to be greatest in the growth seasons of winter and spring.[116] The Western Australian wheat belt is likely to be affected more by climate change than central western NSW.

While some aspects of agricultural planning can operate over very long timescales, planting decisions must still be made at the beginning of every season. It is in the nature of agriculture that such decisions carry inherent risks, but some of these could be mitigated if improved forecasts of year to year rainfall and variability were available.

Households

Households are recognized in all affluent societies as an important site of climate change governance for both mitigation and adaptation. In Australia, calculations about household contributions to national greenhouse gas emissions vary depending on the assumptions made about where responsibility is to be attributed: 13% if only direct energy use within the household is considered, and 56% if the emissions embedded in externally produced goods and services consumed in the household context are included.[127] The difference in these figures illustrates not only the difficulty of measurement, but more importantly the conceptual challenge in isolating 'households' as separable units. This is a creative challenge because it helps us consider the different flows and connections within society. Households have been the focus of government policy at all three levels of government, including via support for solar panels, home insulation, water tanks, light globes, shower timers, and education campaigns for sustainability. An emerging body of work helps understand relationships between everyday household practices, cultural processes, and climate change,[128,129] for example, the influence of ethnic diversity.[74,130] Strong environmental beliefs do not necessarily correlate with action; poor households are most likely to be uninterested in climate change

TABLE 5 | Projected Climate Change Impacts on Australian Agriculture for Given Changes in Temperature Relative to 1990.[116]

Change in Temperature	Sector/Industry	Impact
<1°C	Annual milk production per cow	Fall by 250–310 L or 6%
	Total factor productivity of wheat in NSW with lower rainfall	−4.2%, relative to reference case
	Total factor productivity of wheat in WA with lower rainfall	−7.3%, relative to reference case
	Total factor productivity of sheep meat in NSW with lower rainfall	−1.8%, relative to reference case
	Total factor productivity of sheep meat in WA with lower rainfall	−6.1%, relative to reference case
1–2°C	Pasture productivity with 20% lower rainfall	−15%
	Liveweight gain in cattle with 20% lower rainfall	−12%
3–4°C	Tick-related losses in net cattle production weight	Increase by 128%

TABLE 6 | Examples of Features that Differentiate the Incremental and Transformative Decision-Making Processes Undertaken by Wine Industry Stakeholders

Incremental adaptation	Focus on change management for the short-term. '*We're worried about what we do next week rather than what we're doing in seven or 10 years time*'.
	Reactive management of change, focusing on current conditions. '*I think we're more reactive [than] proactive. I don't think that there's any kind of looking at the tea leaves and saying this is going to happen to the climate so therefore we should do this*'.
	Change management is focused on finding ways to keep the present system in operation. '*My view is that if you haven't got enough water, then you move the water to the location; you don't move the location to the water*'.
Transformative adaptation	Proactive management of present and future change, with a view to influencing it. '*We actually try and create the market for it and then plant the vines*'.
	Uncertainty in the future is acknowledged and built into decision-making. '*We don't factor on - now two degrees, the number might be wrong but it's still the thinking. We're going to accept that there's going to be at least two degree temperature rise*'.
	Managing change includes questioning the effectiveness of existing systems and processes. '*We just can't keep our decision making process the same*'.

These examples relate to the initial stage of the adaptation action cycle; problem structuring and establishing the adaptation arena.[138]

but also least likely to have high consumption.[131] Norms of cleanliness influence water consumption,[132] domestic tanks do not save as much water as predicted but water restrictions are accepted and effective if enforced equitably.[133] Smart meters do not challenge practices considered nonnegotiable, such as appliance use.[134] Cohabiting extended families share some things but not others.[135] There is considerable cultural resistance to eating low-emissions kangaroo meat.[129]

The point of focusing research activity at the household scale is not because this will be the social unit to bear all the responsibility of government policy on climate change—although some public discussion of carbon pricing in Australia seems to promulgate such a view. Rather, household research illustrates how greenhouse gas emissions, mitigation actions, and adaptive strategies can all emerge—sometimes simultaneously—out of the same site or community. Households, and research into their everyday workings, provide an imaginative resource to envisage alternative possibilities of shared responsibility, risk-bearing, and social transformation. As further illustration, the more detailed indigenous example below shows also that adaptation capacities and vulnerabilities are uneven, but that creative solutions can emerge from contexts of strong social need.

Transformational Adaptation

The biodiversity, agriculture, and emergency management examples show the combination of incremental and transformative changes happening and potentially necessary. There is an emerging literature on transformational adaptation, not only to a possible 4° warmer world, but also to the increased level of surprise and uncertainty associated with rapid change in complex systems. Australian researchers are contributing productively to this research conversation,[136,137] for example, in comparing incremental and transformative decision-making processes in the wine industry[138] (Table 6).

The tension between such research and the more gradualist assumptions implicit in most policy approaches is illustrated in some of the discussion associated with the Productivity Commission's recent Report on Barriers to Climate Change Adaptation.[139] Our focus on this example is not to engage with any specific recommendations, nor to fully engage with the complex question of where, how and to what extent governments should be involved in adaptation, both of which would be beyond the scope of this overview, but rather to show that there is a live and emerging debate over how adaptation is mostly conceptualized and framed. Commenting on the draft report,[140] the CSIRO supported most of the specific recommendations, but noted:

> However, the Draft Report has a framing which CSIRO believes underestimates the challenges of adaptation policy and action by governments, industries and communities.
>
> CSIRO considers that this framing overstates the degree of uncertainty about future climate change and the inability of people to make decisions in the face of this uncertainty. We also consider that the Draft Report overstates the inherent capacity of individuals, communities and industries to act, and act in a proactive way.
>
> As a consequence of this framing CSIRO is of the view that the Draft Report underestimates the

TABLE 7 | Examples of Transformational Adaptation for 4° of warming.[142]

Governance	Significant changes to social policy to manage changing expectations of living standards and way of life.
	Alternative governance arrangements in place as local governments become increasingly unable to cope, particularly in coastal areas.
Coastal settlements	Policy and planning mechanisms in place necessary to redesign and/or relocate urban settlements as required in response to climate change threats, while maintaining/enhancing liveability.
	Put policies in place to manage a tendency by the private sector to withdraw from insuring risk, so that it is appropriately shared with the public sector. This could translate to more assertive policies to reduce risk and clarify responsibility.
Infrastructure	Significant reform of consumer expectations of the reliability of service delivery.
	Repositioning of facilities for dealing with waste water (sewage) to avoid pump outages due to flooding and consequent contamination of other water bodies & supplies.
Financial institutions	Some level of private insurance is compulsory. Premiums are directly linked to the assessed risk of individual assets. Some residual risk resides with asset owners. Significant reform of consumer expectations regarding insurance coverage.
	Investment decision frameworks are integrated with public sector contingency funding to coordinate appropriate investment responses to extreme events.
Water	Rural—Transformation and relocation of agricultural production – different outputs using different farming systems, input mixes, and in different locations.
	Urban—Complete cultural change to urban water use reflecting increased scarcity and unreliability of supply.
	Demand managed effective through pricing and allocation, support by water-efficient urban design.

> risks to Australia, resulting in a generally superficial analysis of the role of government in adaptation across the economy. This includes not undertaking a quantitative assessment of the economic costs and benefits of different interventions to support the recommendations.[141]

The final report did contain a number of changes from the draft report, including removal of the controversial statement that 'Most adaptation would occur without the need for government intervention' (draft report p. 7). It also quoted the CSIRO advocacy of the need to consider non-stationarity, nonlinear change, and emergent properties (final report p. 96), but did not build such thinking into any recommendations. The examples of transformational adaptation provided in the CSIRO submission (Table 7) are quite different in tone and scope. For example, whereas the Productivity Commission report looked at the priority reforms needed at different levels of government[139], CSIRO highlighted the need for 'Alternative governance arrangements in place as local governments become increasingly unable to cope, particularly in coastal areas.' The CSIRO submission and other discussions of transformative adaptation allude to the necessity of alternative governance mechanisms, and the necessity for these to interact with existing levels of government. In the wider Australian polity this conversation is yet to really begin.

AUSTRALIAN INDIGENOUS COMMUNITIES AND CLIMATE CHANGE

The Australian indigenous population is around 575,000 people (2.5% of the Australian population). Indigenous people from mainland Australia are usually termed Aboriginal, with Torres Strait Islanders forming a culturally distinct indigenous group from the islands between Australia and Papua New Guinea; within both these broad groupings there is significant diversity. While there is an increasing concentration in urban areas, one quarter of indigenous people live in remote or very remote areas. Some of this relatively small latter group owns and manages around 23% of the continent, albeit very unevenly distributed geographically and demographically. Much of it is in arid, semiarid and, tropical zones, including significant areas of coastline (Figure 5).

Numerous reports[143] have identified the paradox that while they may contribute the least to climate change, indigenous communities globally are amongst the most vulnerable to its impacts. Low socioeconomic status, dependence on natural resources, residence in particularly vulnerable geographic regions, and histories of inadequate policy response in settler states, all create increased vulnerabilities. Conversely, some

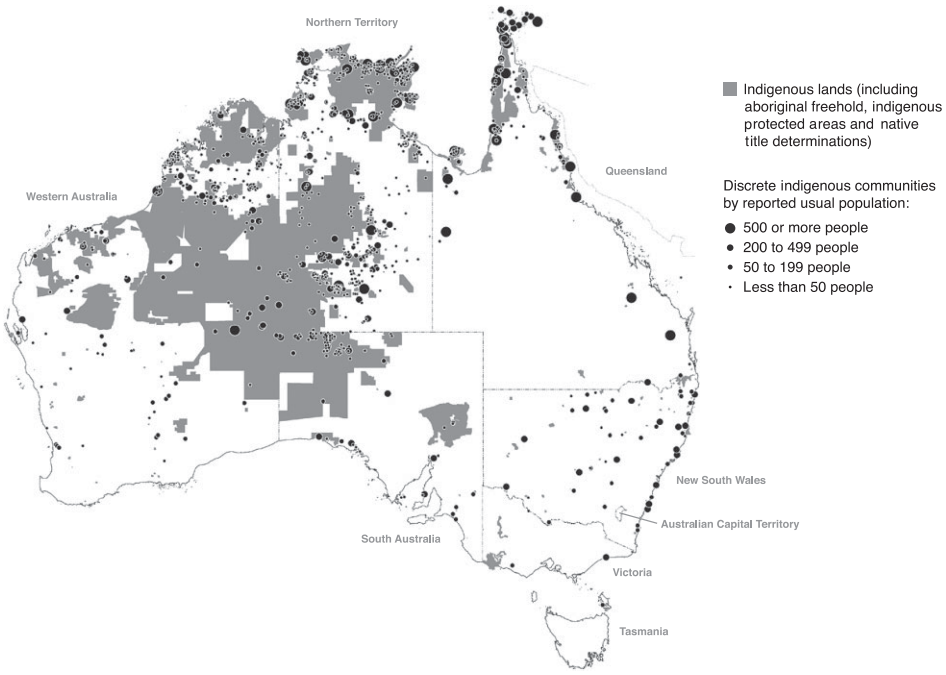

FIGURE 5 | Map of the Indigenous estate in Australia at 2010, also showing discrete indigenous communities.[5]

cultural characteristics may mean that some indigenous communities are well placed to develop effective adaptive responses to climate threats, and indigenous knowledge systems may contribute significantly to understanding climate change.

Significant focus in research has been on health outcomes. In Australia, a 200-year history[144] of institutionalized racism and inadequate policy has meant that Aboriginal and Torres Strait Islander people have the lowest status of all subgroups for most indicators (for example health, education, income, and housing).[145] They may be particularly vulnerable to health impacts from climate change,[146] e.g., an increase in mosquito-borne diseases in remote northern locations, increased nutrition-related illness due to decreased opportunities to access wild resources, and increased mental health impacts because 'connection to country' is often seen as a strong element of Aboriginal culture.[147,148]

There is potential for strong contributions from indigenous knowledge systems to understanding and responding to climate change.[149] Intimate and detailed knowledge of biophysical environments over long time frames means changes are often observed and noted. Indigenous knowledge systems are typically adaptive,[150] so responses such as adjusting times for carrying out traditional burning (in response to changed humidity and rainfall for example) are already occurring. Most national park agencies have developed climate change strategies that include indigenous cultural heritage management.[151,152] The nature of indigenous land holdings also offers unique opportunities for creative responses to climate change issues (see Box 2). The development of the Indigenous Protected Area (IPA) system since 1995 has had significant benefits for both indigenous communities and biodiversity and heritage conservation.[153,154] IPAs are unique in retaining indigenous authority and control, allowing specifically indigenous responses to both biophysical and cultural dimensions. Recent innovations in IPAs are embracing multi-tenure and marine contexts,[155] both significant in climate change responses. Indigenous people have been excluded from river management processes across the country, resulting in calls for recognition of the unique Indigenous relationships to water (cultural flows) now being promoted in diverse landscapes across Australia. Cultural flows attempt to maintain the spiritual, cultural, environmental, social, and healthy livelihoods of indigenous peoples, recognizing the significant over-allocations of water for commercial purposes.[156,157]

Analysis of the relationships between indigenous cultural characteristics and climate change impacts suggests both strengths and weaknesses.[161] The maintenance of extended kinship networks can exacerbate residential overcrowding in situations of inadequate housing, widespread in both urban and rural and remote locations. Overcrowding can then lead to increased health vulnerabilities. Conversely, the same extended kinship networks

BOX 2

CARBON MANAGEMENT ON INDIGENOUS COUNTRY

Australia's carbon tax is heavily reliant on carbon offsetting by industry. Although the effectiveness of offsetting is controversial, several such schemes on indigenous country provide social, economic, and cultural benefits as well as mitigation ones.[158] The West Arnhem Land Fire Abatement program (WALFA)[159] uses offset payments from a gas producer to support a cultural savannah burning strategy that continues knowledge and culture while simultaneously maintaining high biodiversity and reducing carbon production from wildfire. In 2000, savanna fires caused 40% of official greenhouse gas emissions in the Northern Territory, accounting for 2–4% of Australia's total greenhouse gas emissions. In its first 5 years, the WALFA scheme reduced emissions by the equivalent of more than 707,000 tonnes of CO_2. New national policy initiatives such as the Carbon Farming program are attempting to engage further with indigenous landholders to develop combined environmental and economic outcomes, including a targeted Indigenous Carbon Farming Fund.[160] WALFA is inspiring other schemes, such as those developed over the last 2 years by Aak Puul Ngantam ['Our father's father's country'] Ltd in Cape York. APN contributes to local livelihoods, employing more than thirty local people, and facilitating education of children on their traditional country.[158]

may generate significant social capital and broader exchange networks that may offset decreased access to appropriate food and other resources. The highly mobile nature of many indigenous families can increase possibilities for relocation due to, for example, extreme coastal weather events. Many indigenous communities exist at the peripheries of government and civil support, both geographically and in policy terms. While this obviously increases vulnerabilities, it also means that communities are often used to being self-sufficient and may respond more effectively to breakdowns in civil services. For Australian indigenous people, emergency management can be particularly fraught. A history of state-sanctioned forced removals and dispossession means there is significant distrust, and a strong potential for evacuations to become relocations, separating people from their homelands.[162]

Existing research has focused on remote and rural communities, with many place-based studies in national parks, areas of Aboriginal,[163] and Torres Strait Islander[164,165] homelands, and a particular focus on northern Australia. There is a distinct lack of research on urban communities, a significant gap as nearly a third of the indigenous population is now primarily resident in urban areas.[166]

CONCLUSION

We have outlined the impacts of current and projected climate change on a predominantly arid continent that has long experienced spatially and temporally variable climatic conditions, supporting a human population clustered in coastal cities via a fossil-fuel based economy. With over a quarter-century of intermittent steps toward mitigation, the nation has recently instituted a price on carbon to shift the economy toward renewable energy provision over the next few decades. Although there has been some history of bipartisan action toward climate change mitigation, that is not the case at present, and with a Federal election due in September 2013, the carbon pricing legislation may not survive a change of government.

Just as the Anthropocene itself is relatively rapid in geological terms, a quarter-century to slow down and start to turn around a high emissions economy is also relatively rapid, given the exponential trajectory of post-World War II growth. But that now looks to be about two decades too long. For political, intellectual, and cultural reasons both mitigation and adaptation actions have been framed in gradualist terms to garner the necessary public support, against vociferous opposition from a range of vested economic interests.[167] Those gradualist responses, while significant achievements, now look to be insufficiently transformative to deal effectively with extreme or step-changes in which significant thresholds will be crossed.

On the basis of this review, the maintenance of existing research efforts and investment is critical. (Yet at the time of writing the National Climate Change Adaptation Research Facility is about to run out of funding.[168]) We also identify four additional areas of significant research and policy priority.

1. Both mitigation targets and adaptation scenarios in Australia are framed in terms of gradualist change increasingly at odds with scientific discussion of the need to keep fossil fuels in the ground, and the possibility of a four degree warmer world. We argue that it is therefore time for the research community to

pay systematic attention to mechanisms and processes of transformative change, by which we mean profound, unwanted and probably forced change at a scale of years as well as decades and centuries. Where are the pressure points most likely to be felt, and thresholds crossed, in economic processes, in biodiversity, in agricultural production and food security, in the insurance industry, in domestic experience, in social cohesion? We do not suggest that research try to be precisely predictive, rather that at least some of us need to be thinking systematically about worst-case scenarios.

2. A major challenge to assist forecasting is to understand the climate drivers that generate Australia's high year-to-year rainfall variability. Significant progress has been made in this endeavor with a greater understanding of drivers such as ENSO and the indian ocean dipole (IOD) leading to improved predictions; however, given that the drivers themselves may be changing in response to higher greenhouse gases the scientific community must be supported to address this challenge and continue to provide meaningful climate forecasts for Australian industries, agriculturalists, water managers, and communities.
3. Australia is well known for its strong civic (both professional and volunteer) capacities in the management of emergencies such as fire, flood, and drought. If the changes ahead of us become more extreme, it is important to also ask which cross-cultural capacities and traditions within Australia's multicultural communities provide the most useful resources for effecting and coping with transformative change? The stoic bush family facing drought, and the heroic volunteer fire-fighter are powerful cultural myths; they need to be joined by more diverse experiences that recognize everyday capacities as well as vulnerabilities. Research has begun to engage with these questions, but there is much more to be done.
4. What combinations of strong government (federal, state, and local) and more dynamic community responsibility are likely to be necessary and viable? We have discussed some experiments in indigenous land management over the last two decades or so (IPAs, joint management of National Parks, partnerships with environmental NGOs) that may provide wider inspiration for more creative mechanisms. These provide one example; urban households provide another very different scale of governance. Each has its own complexities. Alternative and additional governance mechanisms in the future will need to be envisaged in forms that invest in both social and ecological capital.

Postscript

The Federal election on September 7 resulted in a decisive win to the Liberal-National Party Coalition. Prime Minister-elect Abbott immediately began a process to get rid of the carbon pricing legislation. As the Coalition faces a hostile Senate until at least mid-2014, when new senators will take their seats, the process for undoing the legislation may not be straightforward. The Labor party and the Greens, who together could command a Senate majority until mid-2014, have declared their intention to oppose any attempt to repeal the legislation[169] .

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