Climate change

1 Why is it important?

Earth's surface is warming rapidly, and our global climate is changing, with impacts already discernible to the present generation. Rising air temperatures, increasing severity and frequency of heatwaves, changing rainfall patterns with more extreme and frequent drought and flood, altered ocean temperature and chemistry, and sea level rise all present potential significant risks to our environment, economy, society and way of life.

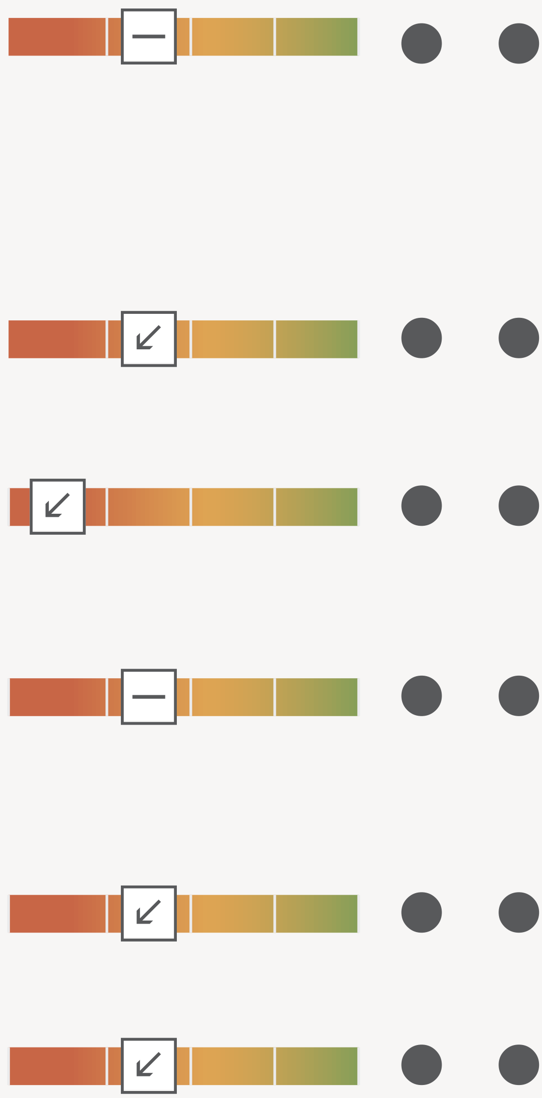
South Australia is already seeing the effects of climate change (Box 1). South Australia's future climate challenges include:

- securing a reliable urban water supply
- coping with the effects on
    - agricultural productivity of higher temperatures, more frequent extreme weather events, reduced rainfall and greater variability of rainfall distribution
    - biodiversity of higher temperatures, reduced and altered patterns of rainfall, and changes in the severity and frequency of extreme weather and bushfire
    - coastal settlements, infrastructure and coastal ecosystems of sea level rise and storm surge
    - marine ecosystems, fisheries and aquaculture of warmer, more acidic oceans and altered ocean currents
    - human health and infrastructure of an increased number and severity of heatwaves, bushfires and extreme weather events.

Opposite page: The junction of the River Murray with the Southern Ocean, 1846
State Library of South Australia B15276/43

In summary

Aspect and observation | Assessment grade (Very poor, Poor, Good, Very good) | Confidence (In grade, In trend)



State greenhouse gas emissions

Per capita emissions and emissions per unit of gross state product have decreased.

Per capita emissions are still one of the highest in the world.

Atmospheric concentrations of greenhouse gases are increasing.

State sources of greenhouse gases are increasing.

Rainfall

The reporting period includes the third and fifth wettest years on record.

The long-term trend is for a decline in rainfall.

Temperature

The reporting period includes the warmest year on record.

The long-term trend is for increases in average (air and sea surface) and extreme temperatures.

Energy

Energy production is still the dominant source of state emissions (74%).

Renewable energy has increased as a proportion of total installed capacity and of the proportion supplied and used.

Sea level

The global trend is for a rise in sea level, with variances based on local geomorphology, wind direction/strength, etc.

Oceans

Sea temperature and acidity are increasing; salinity is changing.

Aspect and observation	Assessment grade (Very poor / Poor / Good / Very good)	Confidence: In grade	Confidence: In trend
Marine and terrestrial biodiversity Trends in biodiversity are negative to variable, with changes in gene pools, species ranges, biological patterns and ecosystem dynamics.	Poor, Deteriorating	Adequate high-quality evidence and high level of consensus	Adequate high-quality evidence and high level of consensus
Human health, infrastructure, agriculture and forestry Reduced rainfall will affect water supplies and agriculture. Climate variability has increased, leading to increased frequency and severity of some extreme weather events such as heatwaves. The increased frequency of extreme events will impact police, emergency services, infrastructure maintenance, volunteers, etc.	Poor, Deteriorating	Adequate high-quality evidence and high level of consensus	Adequate high-quality evidence and high level of consensus

Recent trend: Improving; Deteriorating; Stable; Unclear

Level of confidence:
- Evidence and consensus too low to make an assessment
- Limited evidence or limited consensus
- Adequate high-quality evidence and high level of consensus

Grades: Very poor; Poor; Good; Very good

Box 1 The critical decade: extreme weather for South Australia

Hot days and heatwaves

- The summer of 2012–13 was the hottest on record and included the highest sea surface temperatures on record for the Australian region.
- In Adelaide, from 1993 to 2006, an increase in total hospital admissions of 7% was recorded during heatwave periods compared with non-heatwave periods.
- The nature of heatwaves has already changed in many parts of Australia. Over 1971–2008, the duration and frequency of heatwaves have increased, and the hottest days during a heatwave have become even hotter.
- In Adelaide, the long-term average (1961–1990) number of days per year above 35 °C was 17.5, but during 2000–09 the average number of such days rose to 25.1. This increase is more rapid than climate model projections.
- Research at the Natural Hazards Research Centre has shown that heatwaves are the most significant natural hazard in Australia in terms of loss of life.

Rainfall

- Over 2010–11, every state and territory had sites that either set all-time rainfall records for a two-year period or were very much above average.
- Across Australia, it is more likely than not that heavy rainfall events will become more frequent as the temperature increases.

Drought

- During 2002–03, drought is estimated to have reduced Australia's agricultural output by 26%.
- During the drought of 1997–2009, the inflows into the Murray–Darling system were the lowest on record.
- In 2006–07, it is estimated that drought reduced national gross domestic product by almost 1%.
- For both south-west and south-east Australia, nearly all of the climate models used in a recent analysis project a significant increase in drought by the end of the century.

Bushfires

- The Forest Fire Danger Index, one of the measures of bushfire threat, increased significantly at 16 of 38 weather stations across Australia between 1973 and 2010, with none of the stations recording a significant decrease.
- The increase has been most prominent in south-east Australia, and has been manifest as a longer duration fire season, with fire weather extending into November and March.

Sea level rise

- A sea level rise of 0.5 metres (compared with 1990), which lies near the lower end of the estimates for 2100, leads to surprisingly large impacts.
- For coastal areas around Australia's largest cities, a sea level rise of 0.5 metres would lead to very large increases in the incidence of extreme events, typically by a factor of several hundred and, in some places, by as much as one thousand.
- A multiplying factor of 100 means that a so-called one-in-a-hundred-year event would occur on average every year.

Source: Climate Commission (2013)

Starfish Hill wind farm
Department of Manufacturing, Innovation, Trade, Resources and Energy

2 What do we know about it?

Strong and clear evidence supporting climate change science has been derived from a range of sources, including our historic climate record (palaeoclimatic evidence from tree rings and lake sediments, etc.), climate measurements from the recent past and sophisticated climate models. A number of scientific disciplines contribute to our understanding of climate change, including atmospheric physics, chemistry, biology, oceanography, hydrology and geology.

2.1 Past climate change

Climate change refers to long-term change in the average pattern of weather over decades or longer. Earth's climate has varied enormously many times since Earth formed 4.5 billion years ago; it has been both warmer and cooler than today, driven by changes in the sun's intensity, Earth's orbit around the sun, the changing configuration of continents and oceans, and natural variations in the level of greenhouse gases in the atmosphere (Australian Academy of Science 2010, CSIRO 2011).

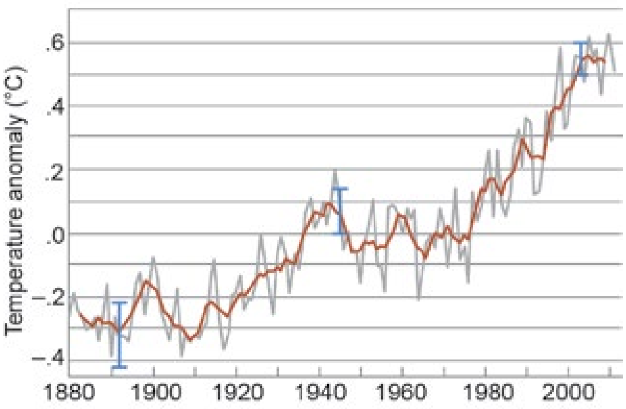
The geological records show us that past temperature changes have affected the world dramatically, altering atmospheric and oceanic circulation, rainfall patterns and water availability, ice cover, vegetation, ocean acidity and sea level. Past climate change also shows us that global climate is sensitive to small influences (Australian Academy of Science 2010). Processes similar to past climate change can act to amplify current human influences.

Our evolutionary history can be, at least in part, linked to past climate change, with a growing body of work in palaeoanthropology showing a correlation between evolutionary events and times of natural climatic variability. Modern human civilisation has evolved and developed during a relatively stable period of climate following the last glacial period, known as the Holocene. Humanity has dealt with small variations in climate in the past. However, recent human-induced climate change presents a challenge for today's much larger and more urbanised population, which depends on complex infrastructure and globally interdependent agricultural systems (CSIRO 2011).

2.2 Current climate change

Our current climate is changing far more rapidly than in the geological past. Global average temperatures both on land and over the ocean rose by just over 0.7 °C in the 100 years from 1910 to 2009 (Figure 1). Average surface air temperature has increased by nearly 1 °C in Australia and South Australia, higher than the global average, and will continue to rise (Climate Commission 2011a, CSIRO 2011). The rate of global warming is increasing, with the past 50 years warming at nearly twice the rate as over the past 100 years (CSIRO 2011). South Australian average temperatures have been rising steadily since the 1970s, and temperatures for the past decade (2001 to 2010) were the warmest since records began in 1900 (BoM 2011). There has been a clear decline in average rainfall in southern Australia since 1970, which has been linked to rising temperatures, and this drying trend is likely to persist.

Around the world, many changes have been observed that are consistent with the increase in global average temperature: warming oceans, widespread retreat of mountain glaciers and ice caps, ice loss from the Greenland and Antarctic ice sheets, sea level rise, continued decreases in the extent and volume of arctic sea ice, increasing water vapour in the atmosphere, decreasing ocean alkalinity, shifting weather systems, and changes to animal and plant behaviour (Australian Academy of Science 2010).



Note: The blue bars show uncertainty estimates.
Source: NASA and GISS (2012)

Figure 1 Global annual mean surface air temperature change, 1880s to the present

2.2.1 Causes of climate change

Greenhouse gases are those gases in Earth's atmosphere that selectively absorb radiation. They are transparent to incoming short-wave solar radiation but absorb the longer wavelength radiation emitted by Earth. This means that atmospheric greenhouse gases have little effect on incoming solar radiation but absorb outgoing radiation, thereby warming the lower atmosphere and surface of the planet. The basic physical principle—that greenhouse gases such as carbon dioxide trap energy emitted by Earth and keep the planet warmer than it otherwise would be—was established more than a century ago.

There is compelling evidence that the recent global warming is being caused largely by human emissions of greenhouse gases, emitted since the start of the agricultural and industrial revolutions (Australian Academy of Science 2010). Scientific understanding of anthropogenic climate change has been built over a long period and continues to advance strongly.

Given the complexity of the climate system, some uncertainties remain in the science of climate change, but these relate more to precise timescales or magnitudes of expected future impacts and do not affect the major conclusions (Australian Academy of Science 2010, Climate Commission 2011b).

2.2.2 The future of climate change

Projections of future climate are dependent on the level of future human greenhouse gas emissions and how the climate system responds to these emissions. It should be noted that there is generally a significant period of time before changes to the inputs of the climate system result in changes to the system. As a result of these long system lags, existing greenhouse gas concentrations in the atmosphere will commit Earth to a further warming of 0.5 °C, irrespective of future levels of emissions (CSIRO 2011).

A number of future greenhouse gas emission scenarios have been published by the Intergovernmental Panel on Climate Change (IPCC) (Box 2). Climate models have enabled projected warming to be estimated for these different emissions scenarios. While it is considered too early to reliably assess which emissions scenarios are the more likely, the lack of global effort to reduce emissions has focused recent attention on the high-end scenarios for mapping our future (Betts et al. 2011). Since the emissions pathways were produced in 2000, there have been unprecedented increases in global emissions of greenhouse gases, reflecting ongoing high emissions levels in developed nations, coupled with the very rapid industrialisation of many developing nations, particularly China and India (Anderson and Bows 2011). Not only are global emissions increasing, but the rate at which they are increasing is growing. Between 2003 and 2007, actual emissions rose at a rate faster than the highest emissions scenario (A1FI) and, despite a temporary slowdown due to the global recession, emissions growth reached a record high in 2009 and 2010 (IEA 2011, Peters et al 2012).

In the late 1990s, a globally averaged warming of 2 °C above pre-industrial levels was proposed as the guardrail beyond which the effects of climate change start to have dangerous risks and impacts on water supplies, ecosystems, food production, coasts and human health (Council of the European Union 2004, CSIRO 2011). The characterisation of 2 °C as the threshold between acceptable and 'dangerous' climate change is premised on an early assessment of the scope and scale of the accompanying impacts. More recent research, however, has revised the impacts associated with 2 °C sufficiently upwards that 2 °C can now be regarded as extremely dangerous' (Anderson and Bows 2011). A 2 °C warming may not sound significant—we are used to greater temperature fluctuations on a day-to-day basis—but normal weather variability should not be confused with a sustained increase in average global temperature. The difference in average global temperature between an ice age and an interglacial period is only 5 °C.

Because future temperature increases correlate closely with the cumulative emissions of the main greenhouse gas—carbon dioxide—the dramatic emissions growth in developing nations highlights the urgent mitigation task before us. Reducing the emissions of carbon dioxide will only slow the rate of increase of atmospheric concentrations, rather than stabilise them. Stabilising atmospheric concentrations requires emissions to be reduced to very near zero and even, depending on timescales and pathways to stabilisation, for some existing greenhouse gases to be removed from the atmosphere. The latest scientific assessments emphasise that long-term gradual reductions in global greenhouse gas emissions are insufficient—rapid, deep and ongoing reductions are required (Climate Commission 2011b, CSIRO 2011, Garnaut 2011, New et al. 2011). A number of recent analyses suggest that, without immediate, concerted mitigative action at a global scale, there is now little to no chance of maintaining the global mean surface temperature increase at or below 2 °C, and temperature rises of 3 °C or 4 °C (relative to the pre-industrial period) by as early as 2060–70 are much more likely (Anderson and Bows 2011, Betts et al. 2011, Climate Commission 2011b, CSIRO 2011, New et al. 2011).

Given the difficulty of achieving rapid and large reductions in global emissions, we need to increase our understanding of the impacts of high-end climate change and the implications these have for adaptation planning.

2.3 Concentrations of greenhouse gases

Earth's atmosphere consists mainly (about 99%) of nitrogen and oxygen—non-greenhouse gases that exert almost no warming effect. The natural greenhouse effect is caused by several different gases that exist in very small concentrations but act to maintain a warmer, life-supporting temperature on Earth. Atmospheric concentrations of greenhouse gases are the net result of emissions of gases (sources) and the removal of gases from the atmosphere (sinks). Human activities have increased the concentration of greenhouse gases by increasing sources of greenhouse gases, such as the burning of fossil fuels and industrial processes (e.g. cement production), and reducing sinks through changed agricultural practices and deforestation.

Atmospheric concentrations of greenhouse gases are known from recent measurements taken at a number of monitoring stations around the world (including Cape Grim in Tasmania) and, for past eras, from the analysis of air trapped in ice cores (Figure 2). These observations reveal that atmospheric concentrations of greenhouse gases have been rising over the past 250 years, but particularly in the past few decades, after being relatively stable since the end of the last ice age.

Water vapour, which exists naturally in the lower atmosphere as part of the water cycle, is the most abundant greenhouse gas and accounts for about half of the present-day greenhouse effect (Australian Academy of Science 2010). It is an important greenhouse gas because, although it is not directly influenced by humans, its atmospheric concentration increases as the atmosphere warms, providing an amplifying effect.

The second most prevalent greenhouse gas in the atmosphere is carbon dioxide (CO_2), which contributes about 64% of radiative forcing—the influence of greenhouse gases on Earth's temperature (WMO 2011). CO_2 is also an important gas because a significant fraction remains in the climate system for hundreds to thousands of years (Australian Academy of Science 2010). The influence of CO_2 on the radiation balance of Earth is the largest single contributor to human-induced climate change (CSIRO 2011).

CO_2 is constantly transferred between the atmosphere, oceans and land vegetation as part of the natural carbon cycle. Before human influences, these natural exchanges were largely in balance. Since industrialisation, CO_2 concentrations have increased by about 40%, from 278 parts per million (ppm) in the mid-18th century to 389.6 ppm in June 2012 (CSIRO 2012a). CO_2 levels are rising mainly as a result of the burning of fossil fuels (increasing sources of greenhouse gases) and deforestation (reducing sinks). The Northern Hemisphere's CO_2 concentration, as measured at Mauna Loa Observatory in Hawaii, peaked at 400 ppm on 4 May 2013, 25% higher than in 1960, and increasing at a faster rate than previously. (Continuous monitoring at the observatory started in 1956.) The concentration of CO_2 falls during the Northern Hemisphere's summer when plant growth absorbs the gas, and then goes up again during the colder seasons.

Just over half of the emissions of CO_2 have been absorbed by natural ocean and land sinks, with the remaining 45% remaining in the air and causing atmospheric concentrations to rise (Australian Academy of Science 2010). There has been a recent acceleration of CO_2 emissions since 2000, coinciding with a period of rapid economic growth in China, India and developing economies (CSIRO 2011).

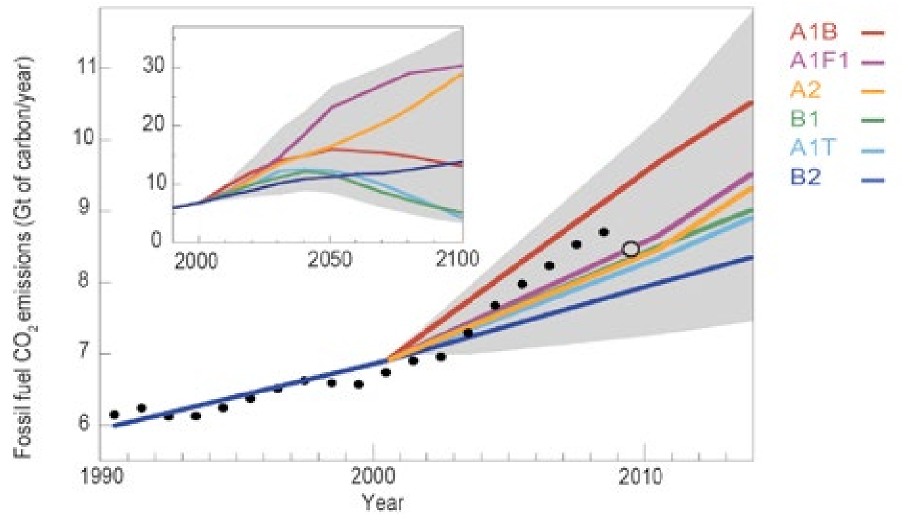
Methane (CH_4) is the next most important greenhouse gas in terms of its impact on the radiative imbalance, contributing about 18% (WMO 2011). Although at a lower concentration in the atmosphere, CH_4 has a much higher warming effect than CO_2 for a given mass. Wetland emissions are the dominant natural source, but, in recent decades, emissions from human activities exceeded those

Box 2 Intergovernmental Panel on Climate Change emissions scenarios

A number of future greenhouse gas emissions scenarios were published by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2000). The IPCC was jointly established by the World Meteorological Organization and the United Nations Environment Programme to assess the scientific, technical and socio-economic information relevant for understanding the risk of human-induced climate change (IPCC 2000). The IPCC emissions scenarios are based on observed emissions until 2000 and then reflect different assumptions about future global population, economic growth and technological development (Betts et al. 2011).

The projected emissions from the IPCC special report are shown in Figure A. Since 2005, global GHG emissions have continued to track above the middle of the IPCC's scenario range—between A1B and A1FI.

The A1FI emissions scenario is the highest emissions category, characterised by an integrated world with rapid economic growth, an emphasis on fossil fuels and a global population that reaches 9 billion in mid-century. The A1FI scenario is considered by the IPCC to be one of a number of plausible future greenhouse gas projections if our global society does not take mitigative action.



Source: Manning et al. (2010)

Note: Black circles represent the years 1990–2008, and the open circle represents 2009. Emissions fall within the range of all 40 emission scenarios (grey shaded area) and six illustrative marker scenarios (coloured lines) of the IPCC special report. The inset in the upper left corner shows these scenarios to the year 2000.

Figure A Annual industrial carbon dioxide (CO_2) emissions for 1990–2008 and 2009

The best IPCC estimate of future warming for A1FI is a 4.5 °C global average surface temperature increase above pre-industrial levels (or 4 °C above 1980–99 levels; Figure A), with a likely range of 2.9–6.9 °C above pre-industrial levels by 2100 (IPCC 2000, 2007). Since the release of the fourth IPCC assessment report, produced in 2007, evidence available from the more recent climate models supports a best estimate of around 5 °C rise relative to pre-industrial temperatures by the 2090s, with a temperature rise of 4 °C by the 2070s. If carbon cycle feedbacks are strong, the 4 °C could be reached in the 2060s (Betts et al. 2011). The other scenarios describe a world with lower emissions and corresponding temperature rises, reflecting differing rates of change in economic structures and different adoption of clean and efficient technologies.

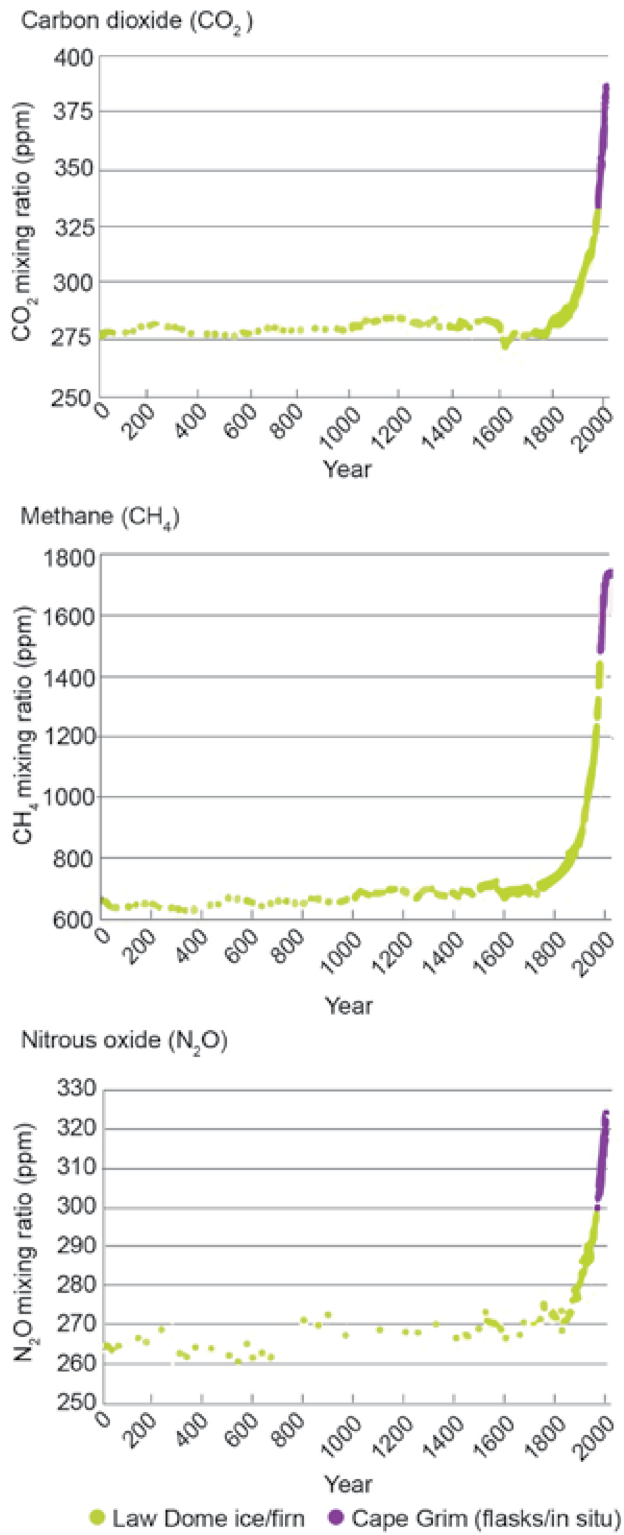
Recently, the IPCC has established a new set of emissions pathways, known as the Representative Concentration Pathways, as the basis for the next stage of scenario modelling and impact assessment (Moss et al. 2010). These differ from the earlier emissions pathways in that they are based on different levels of planned mitigation and consider a wider range of greenhouse gas concentrations.

from natural sources by two-fold or more (CSIRO 2011). Atmospheric concentrations of CH_4 have increased by more than 150% since industrialisation to 1763.7 parts per billion (ppb) in June 2012. Human-induced CH_4 emissions arise from ruminant livestock production; rice cultivation; landfill waste; losses from coal, oil and gas extraction; and biomass burning. CH_4 is removed from the atmosphere through chemical degradation.

The long-term upward trend in CH_4 atmospheric levels slowed between 1999 and 2006 but has been increasing again since 2007. Scientists are currently investigating the possible role of the thawing of the CH_4-rich northern permafrost in this recent increase.

Human-made synthetic greenhouse gases—chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs)—which are used in refrigeration and air-conditioning systems, contribute about 12% to radiative imbalance. Although CFC concentrations are decreasing in the atmosphere as a result of international action to protect the ozone layer, concentrations of HCFCs and HFCs, which are less damaging to the ozone layer and so are being used to replace CFCs, are rapidly increasing. These are potent greenhouse gases with much longer atmospheric lifetimes than CO_2.

Nitrous oxide (N_2O) has contributed about 6% of the overall global increase in radiative imbalance, and concentrations have increased by 20% since industrialisation, to 324.1 ppb. Agriculture is the main anthropogenic source of N_2O emissions, including soil cultivation, fertiliser use and livestock manure management. Fossil fuel burning also produces N_2O (WMO 2011).



Note: Cape Grim measurements are from 1976; older measurements are based on air extracted from ice samples collected from Antarctica (Law Dome).
Sources: Bureau of Meteorology, CSIRO (2012a)

Figure 2 Atmospheric concentrations of carbon dioxide, methane and nitrous oxide

2.4 Observed and projected changes in climate

Global climate change will affect South Australian temperature and rainfall.

2.4.1 Temperature

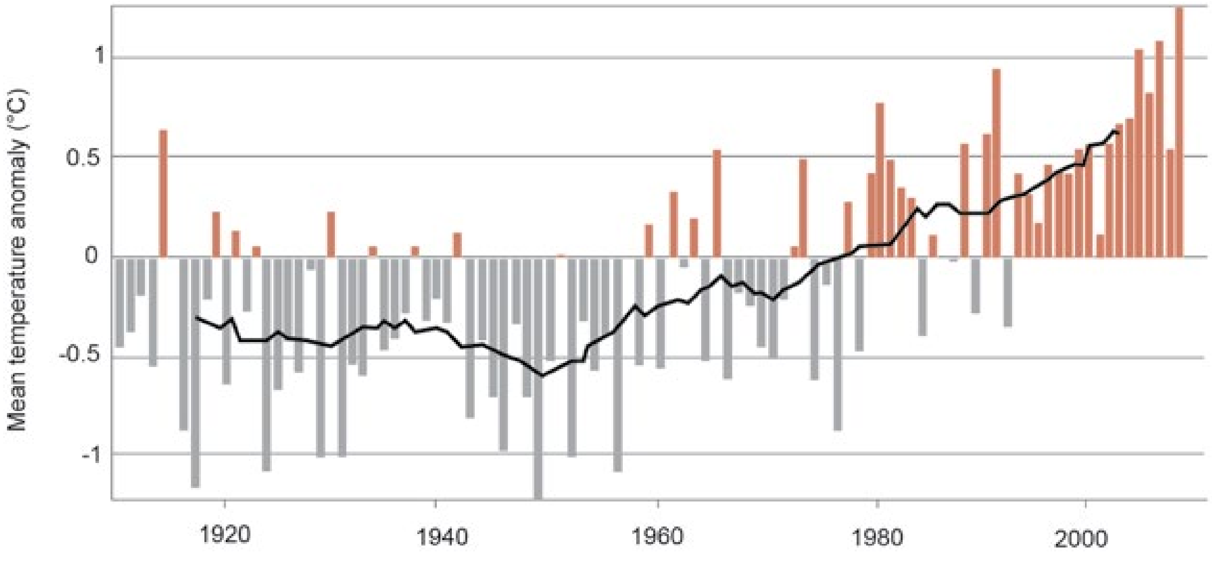
The average South Australian surface air temperature has risen by just under 1 °C over the past 100 years (Climate Commission 2011a), a greater increase than the global average value of about 0.7 °C. Most of this increase has occurred in the second half of the 20th century, and this trend is continuing. The past decade (2000–09) has been the warmest since records began in 1900 (CSIRO 2011). From around 1950, there has been a steady temperature rise—approximately 1 °C—in South Australia (Figure 3).

Minimum (overnight) temperatures increased more rapidly than maximum (daytime) temperatures over most of the 20th century. There has also been an overall increase in the frequency of heatwaves, while the frequency of extremely cold weather has decreased (CSIRO 2011).

The rate of warming of the atmosphere has been moderated by the vast amounts of heat that the oceans have absorbed in recent decades. The upper layer of the ocean has warmed significantly, and recent observations indicate that warming of the deeper waters of both the Southern and Atlantic oceans is also occurring (Climate Commission 2011b).

Global sea surface temperatures also show a warming trend, rising on average by 0.7 °C, while the temperatures of the surface waters surrounding Australia have increased by about 0.9 °C since 1900 (CSIRO 2011).

The latest best estimates for projected additional average temperature increases for South Australia from 1990 to 2030 range from 0.8 °C to 1.5 °C, depending on region and emissions scenario (Table 1). By 2070, additional warming is expected to be between 1.2 °C and 3.5 °C, compared with 1990. These regional temperature projections have been produced by the South Australian Research and Development Institute (SARDI) from a synthesis of the projections contained in the 2006 CSIRO report *Climate change under enhanced greenhouse conditions in South Australia* (Suppiah et al. 2006), and the 2007 CSIRO and Bureau of Meteorology *Climate change in Australia: technical report*. These reports are based on global climatic models prepared for the IPCC (SARDI 2010).



Source: Climate Commission (2013)

Figure 3 Long-term trend in South Australia's average temperature, measured as the difference from the 1961–90 average

Table 1 Best estimate of the range of annual average additional temperature increase in South Australia (relative to 1990) for low–high emissions scenario

South Australian NRM region	2030 (°C)	2070 (°C)
Adelaide and Mount Lofty Ranges	0.8	1.3–2.8
Alinytjara Wilurara	0.8–1.0	1.6–3.5
Eyre Peninsula	0.8	1.2–2.3
Kangaroo Island	0.8	1.3–2.8
Northern and Yorke	0.8	1.3–2.8
SA Arid Lands	0.8–1.5	1.8–3.5
SA Murray–Darling Basin	0.8	1.2–2.8
South East	0.8	1.3–2.3

Note: The temperature ranges are best estimates based on the 50th percentile and range from a low emissions to a high emissions scenario. See the source document for a description of the methods and a full range of results. Note also that the 2030 estimates are largely insensitive to future emissions because of the lag times of the climate system, and therefore show little or no difference under the low and high emissions scenarios. There is some uncertainty in the regional projections as they are based on low-resolution global model results that may not accurately represent regional outcomes.

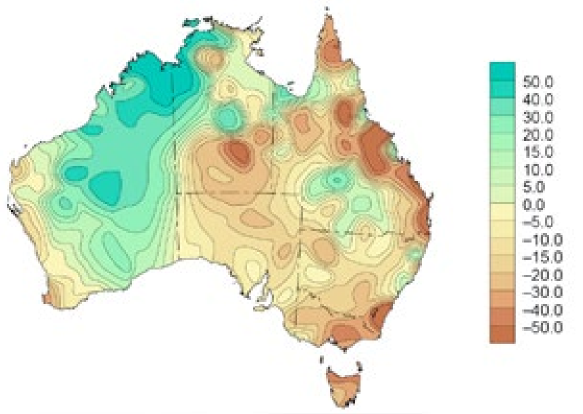
Source: SARDI (2010)

2.4.2 Rainfall

Australia's rainfall has changed over recent decades, with a general trend towards decreasing late autumn and winter rainfall over the south, east and western fringes, but increasing spring and summer rainfall in many parts of the north and west (Figure 4). There has been a clear decline in South Australian rainfall since 1970, which has been linked, at least in part, to changes in large-scale atmospheric circulation associated with global warming (CSIRO 2010).

Year-to-year and decadal rainfall in Australia is influenced by several modes of natural variability caused by changes in relative sea surface temperatures and atmospheric circulation patterns; this results in Australia's rainfall being naturally highly variable over time and from region to region. The modes of variability with the most important impact on Australian rainfall are the El Niño–Southern Oscillation, relating to the tropical Pacific Ocean; the Indian Ocean Dipole; and the Southern Annular Mode, which operates in the higher latitudes (Climate Commission 2011b).

a



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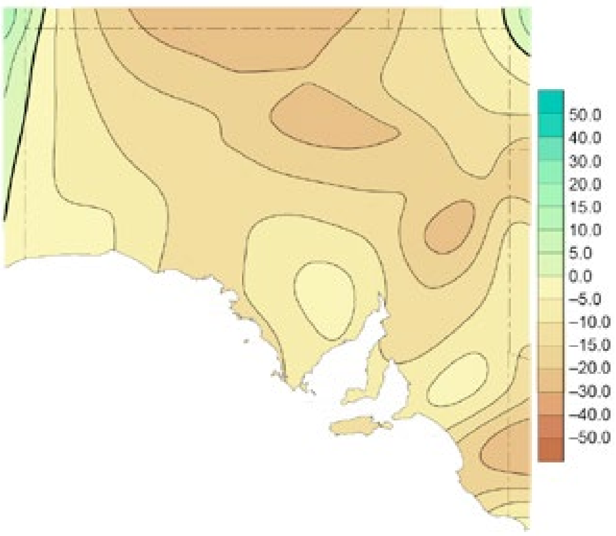


Source: BoM (2012a)

Figure 4 Trends in (a) Australian and (b) South Australian total annual rainfall (millimetres per 10 years), 1970–2011

Although it has been difficult to distinguish human influences on rainfall from natural variations (this is an area of active research), a number of recent studies have detected likely signals of climate change. In particular, a pronounced drying trend that is large compared with historical natural variations has emerged over the past 15–30 years in south-eastern Australia and the south-west of Western Australia (CSIRO 2011).

Higher temperatures and warming oceans affect atmospheric circulation and may be altering the behaviour of these natural modes (IPCC 2010). The Southern Annular Mode (also known as the Antarctic Oscillation) reflects the north–south movement of strong westerly winds in the mid to high latitudes of the Southern Hemisphere that bring storm systems, cold fronts and rainfall to southern Australia. Over the past several decades, there has been an increasing tendency for this mode to remain in a 'positive' phase, with the westerly winds remaining contracted towards the Antarctic, leading to reduced winter rainfall over southern Australia (BoM 2012b).

The Indian Ocean Dipole is a measure of differences in the temperatures of the western and eastern equatorial Indian Ocean. A 'positive' event is caused by warmer than usual waters in the tropical west, and cooler than normal waters (due to altered ocean circulation) in the tropical east. This is associated with a reduction in late winter and spring rainfall over southern Australia. The number of positive events has been increasing since 1950 (reaching a record high frequency over the past decade), while the number of negative events (bringing increased rainfall) has been decreasing (Abram et al. 2008, Cai et al. 2008, Ihara et al. 2008, BoM 2012c).

There is some evidence to suggest that global warming is increasing the likelihood of dry states associated with the El Niño–Southern Oscillation (CSIRO 2010), by causing a weakening of the Walker Circulation in the Pacific and leading to conditions similar to the El Niño phase of the Southern Oscillation. El Niño events are linked to lower spring and summer rainfall in Australia. Climate model forecasts support this weakening over coming decades, but the research in this area is ongoing and is still not settled (Darren Ray, Senior Meteorologist/Climatologist, South Australian Regional Climate Services Centre, Bureau of Meteorology, pers. comm., 24 April 2010).

Recent research has also shown that much of the observed rainfall decline since 1970 in southern South Australia and Victoria is linked to changes in atmospheric circulation via an expansion of the tropics (CSIRO 2010, 2012b). The Hadley Circulation is a fundamental part of the global climate system. It is the atmospheric circulation that transports warm, dry air poleward from the equator. As this cools and sinks, it creates an east–west band of high atmospheric pressure known as the subtropical ridge over the mid-latitudes of both hemispheres (including southern Australia) and is responsible for the relative aridity at these latitudes.

During the warmer half of the year (November to April), the subtropical ridge sits south of the Australian continent and acts to block southern rain-bearing fronts. It then moves north during the cooler months, thereby allowing autumn and winter rains to reach southern Australia. The intensity of the subtropical ridge has been expanding and increasing in strength since 1970, and this correlates well with rising global temperatures over this time. The 13-year period from 1997 to 2009, known as the millennium drought, was the driest in the last 110 years of rainfall records. The millennium drought was unprecedented in that it was largely constrained to southern Australia; there was an absence of wet months and wet years; and the seasonal pattern of rainfall decline differed from previous droughts, with reductions occurring mainly in autumn. The change in seasonality of rainfall contributed to a disproportionately high drop in stream flow: soils were drier at the start of the run-off season because more winter rain was taken up by vegetation and dry soils (CSIRO 2011, 2012b).

Adelaide skyline

Barbara Hardy Institute

One of the implications of these findings for water planning and management is that the traditional filling season of water supply systems across most of south-eastern Australia may not be as reliable in the future. It is also uncertain to what extent the reduced cool-season rainfall will be offset by higher warm-season falls. The expansion of tropical influences on climate will be important in influencing stream flow. Record rainfalls in 2010–11 were brought about by a strong La Niña event (the wet phase of the El Niño–Southern Oscillation), and wet phases of the Indian Ocean Dipole and the Southern Annular Mode, coupled with the warmest sea surface temperatures on record to the north of Australia. Abundant rainfall can still be expected even if, overall, the climate becomes drier. In 2011, late autumn and winter rainfalls continued to be below average, consistent with the expansion of the Hadley Circulation (CSIRO 2012b).

Rainfall predictions do not have as high a degree of confidence as temperature predictions; however, all global climate models generally agree that there will be decreased rainfall in the mid-latitudes, where southern Australia sits (CSIRO 2011). Consequently, South Australia's drying trend is likely to continue, and this, together with higher temperatures, poses significant risks to agriculture and urban water supplies (Climate Commission 2011a).

Estimates for reductions in rainfall for South Australia vary by region, but show the possibility of decreases in annual rainfall across all regions of South Australia, particularly in autumn and winter. Since rainfall is much harder to predict than temperature, the range of possibilities is relatively large compared with temperature projections. The estimates in Table 2 have been produced by the South Australian Research and Development Institute. Since they are based on low-resolution global model results, caution should be exercised, as they may not accurately represent regional outcomes.

Table 2 Best estimate of the range of additional rainfall reductions (relative to 1990) for a low–high emissions scenario

South Australian natural resource management region	2030 (%)	2070 (%)
Adelaide and Mount Lofty Ranges	4.5	8–15
Alinytjara Wilurara	3.5–4	8–15
Eyre Peninsula	3.5	7.5–15
Kangaroo Island	3	8–15
Northern and Yorke	3	7–30
SA Arid Lands	3–4	8–10
SA Murray–Darling Basin	3.5	7.5–15
South East	3	8–15

Note: These rainfall reduction ranges are a best estimate based on the 50th percentile and range from a low emissions to a high emissions scenario. See the source document for the full range of results. Note also that the 2030 estimates are largely insensitive to future emissions and therefore show little or no difference under the low and high emissions scenarios.

Source: SARDI (2010)

Despite a decline in average rainfall, there may be an increase in flood risk due to an increase in extreme rainfall events, driven by a warmer, wetter atmosphere and warmer oceans around Australia (CSIRO 2011). This may particularly occur during wetter phases of natural variability, such as La Niña events, as seen with record rainfall falling across south-eastern Australia over the past two years, coinciding with strong, record-breaking La Niña events (Darren Ray, Senior Meteorologist/ Climatologist, South Australian Regional Climate Services Centre, Bureau of Meteorology, pers. comm., 24 April 2010). This rainfall was unusual because it fell during spring and summer, rather than the normal southern rainfall season.

2.5 Observed and projected impacts of climate change

We are already seeing changes in both marine and terrestrial ecosystems due to climate change. We are starting to see impacts in human agriculture and health, and impacts on infrastructure and water supplies will increase.

2.5.1 Impacts on oceans and marine ecosystems

The world's oceans slow the rate of warming in the atmosphere. More than 90% of the extra heat energy stored by the planet over the past 50 years has been absorbed in the ocean, causing them to expand and rise (ACE CRC 2011). The increasing heat content of the oceans and sea level rise provide further measurable evidence of the warming of the planet (CSIRO 2011). Oceans have also absorbed about 30% of the CO_2 released by human activities during this time, increasing their acidity. Further acidification could have profound effects on organisms that form carbonate shells, such as corals and plankton. These organisms are a critical part of the marine food chain (CSIRO 2011).

Ocean currents are changing as a result of altered patterns of salinity (related to increased evaporation, ice melt and changing rainfall), ocean temperature and winds. Ocean currents are a key component in the distribution of heat around the planet (CSIRO 2011). The Southern Ocean plays a critical role in the global climate system and carbon cycle, because of the unique ocean currents in this region. Vast amounts of heat and about 40% of the total global ocean uptake of anthropogenic CO_2 are absorbed by the Southern Ocean. The Southern Ocean also influences weather patterns over southern Australia. Observations indicate that the Southern Ocean is warming, and becoming less saline and more acidic, while ocean currents are changing (ACE CRC 2011).

Climate change represents a significant risk to the sustainability of ecosystems, fisheries and aquaculture in Australia; however, potential impacts are complex and still largely unknown. In addition to altered ocean temperature, currents, rainfall, winds and chemistry, changes in the nutrient supply (provided by the ocean circulation), altered river run-off into the coastal environment and an increase in extreme events (such as floods and storms) will significantly affect marine life. Australia's marine environment is diverse, with many specialised environments, and the impacts of climate change will differ among them (Hobday et al. 2008).

Projected climate change impacts on South Australia's highly diverse marine environments are likely to be large and negative. Seamounts and inverse estuaries (where the water is more saline than the open ocean, such as the Spencer Gulf) could be subjected to corrosive waters that will preclude or reduce the occurrence of many calcareous species, such as molluscs, and the larval stages of all commercial species. Increases in ocean temperature are causing the range of several species of kelp to contract southwards, and in some cases these species are disappearing altogether from coastal waters close to Adelaide. The combined impact of ocean warming and acidification on kelp is predicted to be profound. The Great Australian Bight is a region of high marine and coastal biodiversity, and many species will be affected by the projected weakening of ocean currents and increased ocean temperatures. The endemic Australian sea lion, 80% of the population of which occurs in South Australia, is a non-migratory animal that is at high risk from climate change as a result of reduced food availability and increased risk of disease, due to rising temperatures and habitat disruption. The leafy sea dragon, South Australia's marine emblem, is likely to suffer from storm events and habitat degradation caused by ocean warming, acidification and sea level rise (NCCARF 2011, Pecl et al. 2011).

A risk assessment of South Australia's 10 most valuable wild fishery and aquaculture species has indicated that 4 of these (southern rock lobster, blacklip and greenlip abalone, and King George whiting) are at high risk from potential climate change impacts. The South Australian coastline has two gulfs, which are zones of upwelling. Upwelling brings nutrients from the deep ocean to shallower waters, providing food for marine ecosystems. Effects of climate change on the marine environment may lead to changes in the frequency and intensity of upwelling events, potentially affecting food availability for southern bluefin tuna and the abundance of sardines. Other stressors, such as overfishing, pollution, habitat loss and disease, are likely to exacerbate the threat from climate change (Pecl et al. 2011). Increased sea water temperatures are expected to increase competition from marine pests to the detriment of native species.

Recent evidence of deaths of fish and marine mammals, and reductions in numbers of regional species, including the giant cuttlefish, seem to be in the short term connected to low oxygen levels from excessive algal blooms caused by high sea water temperature, and could be related in the long term to climate change drivers. There are insufficient data at this time to draw more definite conclusions about the causes.

2.5.2 Impacts on terrestrial plants and animals

Australia and South Australia both have rich species diversity, with many species unique to the continent. Biodiversity is a critical part of our life-support system. It provides us with fresh water, regulation of air and water quality, climate regulation, erosion control, and pest control and pollination services, as well as genetic resources for medicines, food, fibre and fuel (Steffen et al. 2009). Terrestrial biodiversity also has intrinsic, heritage and ethical values. Maintaining biodiversity and healthy ecosystems is important to assist adaptation in other sectors, such as coastal wetlands that protect human infrastructure from storm surges (Hughes et al. 2010).

Climate change will have both direct and indirect impacts on species. Increasing atmospheric CO_2 concentrations can directly affect important physiological processes, such as photosynthesis, plant growth, water-use efficiency and decomposition. Indirectly, climate change acts on species through increasing temperatures, altered patterns of precipitation, and changes in the frequency and severity of extreme events (Steffen et al. 2009). Different responses by species to climate change will result in changes in the structure and composition of many ecological communities and ecosystems (Hughes et al. 2010). Indirect effects from climate change also include disturbance of predator–prey relationships.

Ecosystems are responding in a consistent way to a warming Earth, with observed changes in gene pools, species ranges, timing of biological events and ecosystem dynamics (Climate Commission 2011b). Australian and global observations show that significant impacts are already under way with only a modest amount of warming. Examples include the migration of several bird species to higher altitudes or latitudes, changing fire regimes in southern Australia and the earlier flowering of flora such as the South Australian donkey orchid (TREND 2010). Climate change is exacerbating existing threats to biodiversity from vegetation clearing, introduced species, highly modified and overcommitted water resources, fertiliser and chemical use, urbanisation, agriculture and mining (Steffen et al. 2009).

Both the magnitude and rate of future climate change pose a threat akin to past geological mass-extinction events, with a high risk of an accelerating wave of extinctions this century and beyond (Steffen et al. 2009).

2.5.3 Impacts on human health, infrastructure, agriculture and forestry

Climate change affects human health directly through a rise in extreme events such as heatwaves, bushfires, floods and storms. Indirectly, it affects human health through impacts on natural systems on which we rely and through social, economic and demographic disruptions (CSIRO 2011).

Average temperature increases of 1–2 °C can lead to a disproportionately large increase in the frequency and intensity of extreme weather events. The number of high temperature extremes in Australia has increased significantly over the past decade (Climate Commission 2011b). In March 2008, Adelaide set a heatwave record for an Australian city, with 15 consecutive days of temperatures above 35 °C, and recorded its hottest night in January 2009 during another exceptional heatwave (BoM 2009, DCCEE 2012a). The intensity of the 2009 event—with four consecutive days over 43 °C, accompanied by unusually hot nights—has been linked to a steep increase in mortality from both renal and ischemic heart disease (Nitschke et al. 2011).

Human health is predicted to be adversely affected by the spread of mosquito-borne infectious diseases such as dengue fever, malaria and Ross River virus infection (Doctors for the Environment Australia 2011). The combination of a greater number of extremely hot days and drier conditions in South Australia increases bushfire frequency and intensity, resulting in human fatalities, injuries and burns, and loss of buildings and infrastructure (Climate Commission 2011a).

In addition to the potential damage from extreme events such as bushfire, storms and floods, built infrastructure is at risk from higher temperatures, changed rainfall regimes, altered groundwater and soil conditions, and sea level rise (CSIRO 2011).

Infrastructure impacts are predicted to include:

- increased flooding due to rainfall events that exceed the capacity of stormwater and drainage infrastructure
- structural damage due to increased wind speed and hail intensity during storms
- exacerbated coastal erosion, coastal inundation and damage to coastal infrastructure, including stormwater infrastructure and roads, due to more intense and frequent storm surges
- degradation of road and building materials, and damage to building foundations and gas and water piping caused by higher temperatures, increased flooding and bushfires

- rail buckling and signal failure, and road fatigue, due to increased temperatures
- power disruptions from surges in electricity demand caused by more frequent heatwaves (Engineers Australia 2010).

With most of Australia's settlements in the coastal region, sea level rise presents a widespread risk of inundation and damage to a significant stock of residential housing, commercial buildings and infrastructure, such as ports, roads and railways. Mean sea level rise may lead to eventual permanent inundation of low-lying areas. Sea level rise (combined with more storminess as a result of climate change) will also contribute to extreme short-term coastal inundation events, which may become increasingly severe and frequent in many coastal places. Coastal environments such as beaches, estuaries, wetlands and low-lying islands are at risk of salinisation and inundation in the coming decades. In South Australia, up to 43 000 residential buildings, with a value of $7.4 billion, and 1500 commercial buildings valued at $27 billion have been identified as at risk of inundation (DCCEE 2009).

Increased temperatures, reduced rainfall and more frequent extreme weather events are expected to reduce crop and livestock production in South Australia. Since 1997, South Australia's agricultural regions have experienced a marked decline in growing season rainfall. Forestry and plantation industries are at greater risk from bushfire (CSIRO 2011, DCCEE 2012a). Viticulture is sensitive to climate change on a number of fronts, including changes in mean temperature, extreme temperatures, rainfall, the quality and quantity of water available for irrigation, and the atmospheric concentrations of greenhouse gases (Hayman et al. 2009).

Reduced rainfall and higher rates of evaporation are expected to significantly reduce the reliability of South Australia's water supply, resulting in less water being available for irrigation, domestic use and industry (CSIRO 2011).

Moon over eroded mesas near the Painted Hills, Woomera Prohibited Area
Angus Kennedy

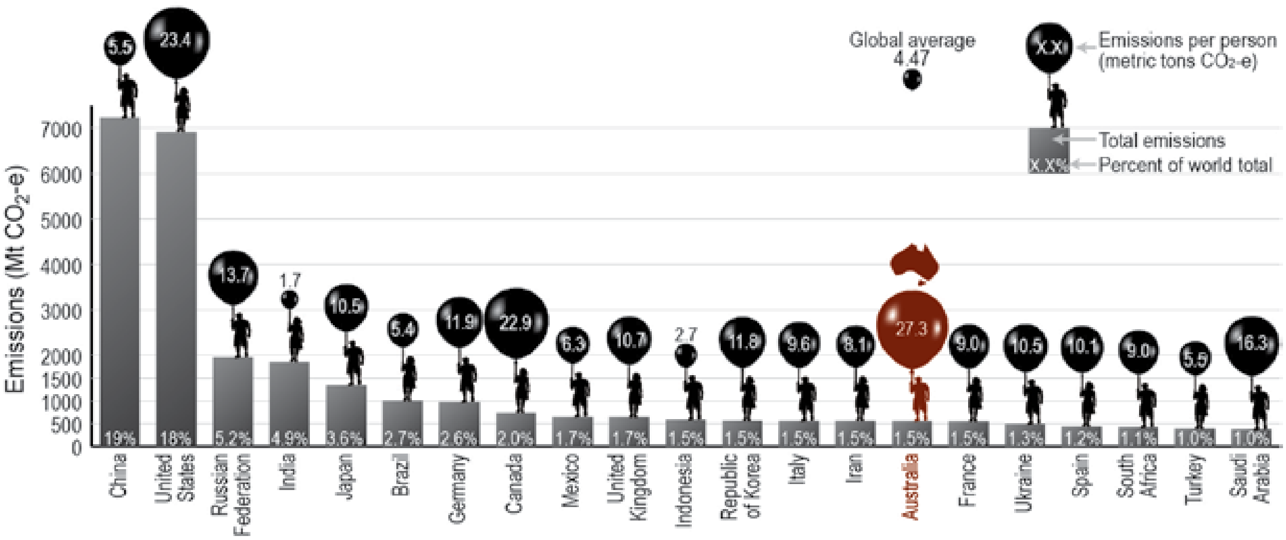
3 What are the pressures?

The key pressure in climate change is the emission of greenhouse gases. Pressure indicators therefore include sources of greenhouse gases, greenhouse gases per head of population and greenhouse gases per unit of economic output.

3.1 Sources of global and Australian greenhouse gas emissions

Global emissions of greenhouse gases have risen steeply since the start of the industrial revolution, with the largest increases coming after 1945. A relatively small number of countries produce the majority of greenhouse gas emissions: the 25 largest emitters produce approximately 83% of global emissions (Table 3). Emissions of greenhouse gases from human sources come primarily from the burning of fossil fuels (coal, oil and gas) to create energy for electricity production, heat generation and transportation. Energy-related emissions accounted for approximately 60% of global emissions in 2000 (Baumert et al. 2005). Deforestation is estimated to account for 15% of global emissions (van der Werf et al. 2009), and agriculture contributes a similar proportion.

Significantly, Australia is one of the top (highest) 25 greenhouse gas emitting nations, ranked 15th in the world based on total emissions in 2005 and contributing 1.5% to total emissions (Figure 5; Table 3). Australia's emissions per capita are the 7th highest in the world, higher than any of the top 25 emitting nations and the highest in the Organisation for Economic Co-operation and Development (OECD) (Garnaut 2008). Compared with other OECD nations, Australia's reliance on coal for generating electricity is a key cause of our high per-capita emissions (Garnaut 2008).



CO_2-e = carbon dioxide equivalent; Mt = million tonne
Source: Baumert et al. (2005)

Figure 5 Global comparison of overall and per-person emissions of greenhouse gases, 2005

Table 3 Top 25 greenhouse gas emitting nations (excluding land use change), 2005

Country	Total emissions (Mt of CO_2-e)	Rank (total emissions)	% of world total	Cumulative %	Per capita emissions (t of CO_2-e)	Rank (per-capita emissions)
China	7 242.1	1	19.2		5.6	82
United States of America	6 900.9	2	18.3		23.3	9
European Union (27)[a]	5 046.7	3	13.4	50.8	10.2	42
Russian Federation	1 939.6	4	5.1		13.5	21
India	1 865.0	5	4.9		1.7	148
Japan	1 349.2	6	3.6		10.6	40
Brazil	1 010.5	7	2.7		5.4	86
Germany[a]	977.5	8	2.6		11.9	28
Canada	741.8	9	2.0		23	10
United Kingdom[a]	642.2	10	1.7		10.7	39
Mexico	631.0	11	1.7		5.9	76
Indonesia	576.5	12	1.5		2.5	120
Iran	568.1	13	1.5		8.1	61
Korea (South)	567.8	14	1.5		11.8	30
Italy[a]	565.6	15	1.5		9.7	49
Australia	560.6	16	1.5	76.7	27.5	7
France[a]	550.3	17	1.5		8.7	55
Ukraine	493.6	18	1.3		10.5	41
Spain[a]	436.7	19	1.2		10.1	45
South Africa	422.6	20	1.1	79.1	9	51
Turkey	390.6	21	1.0		5.7	79
Saudi Arabia	375.3	22	1.0		15.6	16
Poland[a]	372.2	23	1.0		9.8	48
Thailand	351.1	24	0.9		5.3	88
Argentina	328.4	25	0.9	83.0	8.5	58
Top 25	31 361.4					
Countries ranked 26th to 186th	6 435.1	26–186	17.0	100		
Total world emissions	37 796.5					

a European Union includes 27 countries; those in the top 25 are also listed separately. The inclusion of the European Union places Australia 16th in the table.

Note: Excludes bunker fuels (fuels in tanks of marine and air vessels in international transport) and land-use change emissions. 'Land-use change' refers to the emissions and removals of greenhouse gases from human land use, land-use change and forestry activities.
CO_2-e is 'carbon dioxide equivalent', which is a measure of how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of CO_2 as the reference. Gases include CO_2, methane (CH_4), nitrous oxide (N_2O), perfluorocarbons, hydrofluorocarbons, and sulfur hexafluoride (SF_6).

Sources: South Australian Department of Environment, Water and Natural Resources modelling, and global emissions data from the World Resources Institute Climate Analysis Indicators Tool (http://cait.wri.org/cait.php?page=yearly&mode=view&sort=val-desc&pHints=shut&url=form&year=2005&sector=natl&co2=1&ch4=1&n2o=1&pfc=1&hfc=1&sf6=1&update=Update)

3.2 Sources of South Australian greenhouse gas emissions

South Australia contributed 5% of Australian emissions in 2010, at 30.4 million tonnes (Mt) of CO_2 equivalents (including net emissions from the land use, land-use change and forestry [LULUCF] sector—afforestation, reforestation and deforestation activities). CO_2 equivalent (CO_2-e) is a measure of how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of CO_2 as the reference. If the reduction in LULUCF emissions over this period is included (the sector was a 1.5 Mt source in 1990 but a 1.4 Mt sink in 2010, as a result of reduced deforestation and increased forestry plantings), overall net emissions fell by 6%, from 32.2 Mt to 30.4 Mt. Excluding LULUCF, total South Australian emissions increased by 4% between 1990 and 2010 (Table 4).

The energy sector is the dominant source of state emissions, contributing 73% of the total inventory in 2010 (Figure 6). Emissions from the energy sector include emissions from the generation of electricity, the direct combustion of fuels onsite (such as gas and diesel to produce stationary energy), the combustion of fuel for transport and interconnector emissions. Total energy sector emissions (excluding the land-use sector) rose 10% between 1990 and 2010 (Table 3.5). Electricity generation contributed to a 2.6 Mt increase in emissions between 1990 and 2010, with emissions peaking in 2000. The impact of the recent increase in renewable energy generation is evident, with emissions declining slightly in the past few years. However, the underlying electricity consumption in the commercial, industrial and residential sectors has continued to grow.

South Australia has two coal-fired generators: Northern Power Station and Playford B Power Station, both located at Port Augusta. These consume approximately 3.8 Mt of coal annually from the Leigh Creek coal mine (AEMO 2011a). In 2011–12, fossil fuels provided just under 75% of electricity generation, with gas contributing 50% and coal 24% (AEMO 2012).

Transport was the source of 19% of the state's total emissions in 2010. Transport emissions grew by 0.5 Mt (8%) from 1990 to 2010, caused by increasing road freight emissions, while passenger road emissions remained steady over this period (DCCEE 2012b).

Table 4 South Australian greenhouse gas emissions

	Emissions (Mt of CO_2-e)						Change from 1990 to 2010	
	1990	2000	2007	2008	2009	2010	Mt	%
Energy	20.7	21.7	23.6	24.1	22.3	22.1	1.4	7
Net electricity imports	0.6	4.5	1.4	0.4	0.7	1.1	0.5	83
Industrial processes	2.7	3.1	3.3	3.2	2.8	3.1	0.4	15
Agriculture	5.5	5.6	5.1	4.9	4.8	4.7	−0.8	−15
Waste	1.2	0.7	0.7	0.8	0.8	0.8	−0.4	−33
LULUCF	1.5	−2.1	na	−1.3	−1.4	−1.4	−2.9	−193
Total excluding LULUCF	30.7	35.6	34.1	33.4	31.4	31.8	1.1	4
Total including LULUCF	32.2	33.5		32.1	30.0	30.4	−1.8	−6

CO2-e = carbon dioxide equivalent; LULUCF = land use, land-use change and forestry; Mt = million tonne; na = not available
Sources: Australian Government Department of Climate Change and Energy Efficiency, and South Australian Department of Environment, Water and Natural Resources modelling

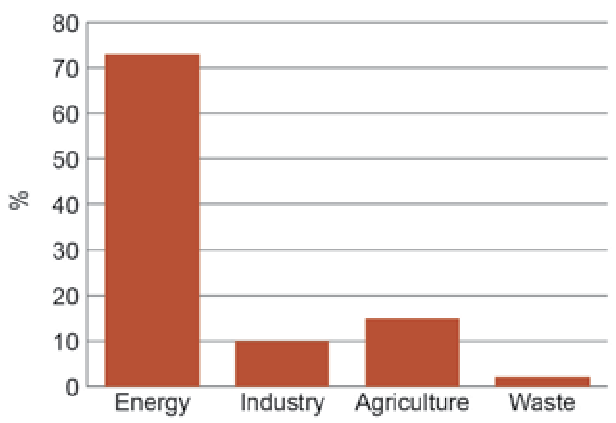
Table 5 South Australian energy sector emissions

	Emissions (Mt of CO_2-e)						
	1990	2000	2007	2008	2009	2010	% change
Electricity (including interconnector)	7.1	11.4	10.7	9.8	9.7	9.7	37
Other stationary energy	4.8	4.8	5.2	5.5	5.5	5.4	15
Transport	5.4	5.8	5.8	5.9	5.8	5.9	8
Fugitive[a]	4.0	4.2	3.2	3.3	2.0	2.2	[a]
Total	21.3	26.2	25.0	24.5	23.0	23.2	10[a]

CO_2-e = carbon dioxide equivalent; Mt = million tonne

a Because of a change in the calculation methodology for fugitive emissions (unintended emissions related to the production, storage, transmission and distribution of fossil fuels) by the Australian Government Department of Climate Change and Energy Efficiency, the 1990 reported figure may be an overestimate.

Sources: Australian Government Department of Climate Change and Energy Efficiency, and South Australian Department of Environment, Water and Natural Resources modelling



Sources: Australian Government Department of Climate Change and Energy Efficiency, and South Australian Department of Environment, Water and Natural Resources modelling

Figure 6 South Australia's greenhouse gas emissions by sector (excluding land use, land-use change and forestry), 2010

Analysis of emissions on an economic sector basis highlights the growth in residential emissions beyond what would be expected as a result of the increase in population. Residential emissions took up a larger share of the state's emissions in 2010 than in 1990. The South Australian population grew by 15% over this period, while emissions from residential electricity increased 33% (Table 6).

3.3 South Australian greenhouse gas emissions per capita

On a per-capita basis, South Australian emissions trended upwards to peak in 2000, but then declined back to 1990 levels by 2007–08. They have fallen below 1990 levels in the past three years, primarily under the influence of increases in the generation of renewable energy in the state (Table 7). This can be contrasted with the Australian trend in the past few years, where, after following a similar upward trend, emissions per capita were at 1990 levels in 2010. South Australian per-capita emissions were substantially (8–22%) lower than the national figures throughout the period 1990–2010.

3.4 South Australian greenhouse gas emissions per gross state product

There has been a 42% reduction in the greenhouse gas intensity of the South Australian economy—that is, the tonnes of CO_2-e produced per million dollars of gross state product—since 1990 (Table 3.8). The similar reduction in the greenhouse gas intensity of the Australian economy has been attributed to a strong growth in the lower emissions service industries and improved energy efficiency (ABS 2010). In addition, Australian manufacturing has been in decline, in parallel with the growth in manufacturing productivity of developing economies (Commonwealth of Australia 2008).

Table 6 Residential electricity emissions and population

	1990	2000	2007	2008	2009	2010	% change
Residential electricity emissions (Mt of CO_2-e)	2353	3606	3392	3154	3080	3137	33%
Population	1 438 882	1 508 028	1 593 743	1 613 346	1 634 468	1 649 947	15%

CO_2-e = carbon dioxide equivalent; Mt = million tonne
Sources: Australian Government Department of Climate Change and Energy Efficiency, Australian Bureau of Statistics. and South Australian Department of Environment, Water and Natural Resources modelling

Table 7 South Australian and Australian emissions per capita

	1990	2008	2009	2010
SA population	1 438 882	1 613 346	1 634 468	1 649 947
SA emissions per capita including LULUCF (tonnes of CO_2-e/person)	22.4	19.9	18.4	18.4
Australian emissions per capita including LULUCF (tonnes of CO_2-e/person)	32.0	26.8	25.9	25.0

CO_2-e = carbon dioxide equivalent; LULUCF = land use, land-use change and forestry
Sources: Australian Government Department of Climate Change and Energy Efficiency, Australian Bureau of Statistics (catalogue number 3101.0) and South Australian Department of Environment, Water and Natural Resources modelling

Table 8 South Australian emissions per million dollars of gross state product and Australian emissions per million dollars of gross domestic product

	1990	2008	2009	2010	% change
SA GSP ($million)	52 043	81 942	83 231	84 269	
SA emissions per $million GSP including LULUCF (tonnes of CO_2-e)	619	391	361	360	–42%
Australian emissions per $million GDP including LULUCF (tonnes of CO_2-e)	797	467	454	434	–46%

CO_2-e = carbon dioxide equivalent; GDP = gross domestic product; GSP = gross state product; LULUCF = land use, land-use change and forestry
Sources: Australian Government Department of Climate Change and Energy Efficiency, Australian Bureau of Statistics (catalogue number 5220.0) and South Australian Department of Environment, Water and Natural Resources modelling

4 What are we doing about it?

The Australian and South Australian Governments are developing policies and programs to reduce the level of climate change by reducing emissions. Governments are also preparing for inevitable climate change by developing guidelines and programs to cope with change.

4.1 Emissions reduction in Australia

The Australian Government has submitted its official emissions reduction targets to the international climate negotiations. Australia has now committed to domestic emissions reductions of 5–15% or 25% (depending on the extent of international action) below 2000 levels by 2020. It has also committed to a longer term target of 80% reductions on 2000 levels by 2050. Existing Australian climate change policies, such as the Renewable Energy Target (DCCEE 2012c) and the Carbon Farming Initiative (DCCEE 2012d), are inadequate to achieve these emissions cuts. Emissions are expected to be around 22% higher than 2000 levels by 2020 without further intervention (DCCEE 2011).

Since electricity generation is Australia's largest source of carbon pollution, the Australian Government introduced its plan for *Securing a clean energy future* (Australian Government 2012) in July 2011. The key element of the Clean Energy Future legislative package, passed in the Senate in November 2011, is the introduction of a carbon price, commencing with a fixed price from July 2012 and moving to an emissions trading scheme in July 2015. The carbon price mechanism will be linked to international carbon markets from the start of the flexible price period, allowing liable Australian businesses to purchase emissions reductions overseas. The carbon price will be supported by the three other elements of the plan: investing in renewable energy, energy efficiency and land-based carbon sequestration (DCCEE 2011).

4.2 Emissions reduction in South Australia

South Australia's key existing emissions reduction initiatives are summarised in Table 9. Given the rapidly evolving nature of climate change policy in Australia, the South Australian Government is currently reviewing its climate change policies and strategies to ensure a fit with the national agenda. South Australia is also working to remove policy and regulatory barriers to reducing greenhouse gas emissions in the state and to facilitate community access to funding from the Australian Government. South Australia is, however, increasingly moving the focus pragmatically from mitigation to adaptation, as efforts in South Australia and Australia are modest in a global context.

Table 9 South Australia's key current emissions reduction initiatives

Initiative	Purpose	Impact and progress
Climate Change and Greenhouse Emissions Reduction Act 2007	To establish voluntary mechanisms to encourage and support action to reduce greenhouse gas emissions and increase the use of renewable energy. The Act includes a long-term emissions reduction target for the state of 60% below 1990 levels by 2050, and renewable electricity targets of at least 20% of electricity generated and consumed by 2014. The Act requires a state government commitment to the development of policies and programs to reduce greenhouse gas emissions, encourage energy efficiency and the commercialisation of renewable energy, and support measures to facilitate adaptation	Between 1990 and 2010, South Australia's net greenhouse gas emissions decreased by 6%, mainly due to the contribution of the LULUCF sector (see Section 3.2). Excluding LULUCF, emissions increased by 4%. The renewable electricity targets have been achieved three years ahead of schedule, and this has slowed the growth in energy-sector emissions. Strong growth trends remain in the energy emissions of the residential, commercial building and industrial sectors. Road freight transport and industrial processes are also growth areas
Tackling climate change — South Australia's Greenhouse Strategy 2007–2020	Provides a framework for meeting South Australia's greenhouse gas emissions targets and commitments in a planned and coordinated way. Lists objectives, strategies and actions grouped by sector (community, industry, energy, transport and planning, buildings and natural resources)	Given the change in national policy, many of the actions currently in the strategy are undergoing review
A renewable energy plan for South Australia (2011)	Outlines the role of the state government in achieving the state's target of 33% renewable energy by 2020 contained in *South Australia's Strategic Plan*	Plan released late 2011
Electricity (Feed-in Scheme—Solar Systems) Amendment Act 2008	To encourage the uptake of residential roof-top solar photovoltaic (PV) systems through the provision of a tariff for electricity fed back into the grid	More than 100 000 South Australian households have now installed or received approval to connect solar panels. As at February 2012, PV systems made up 3% of the state's installed electricity generation capacity (South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy, pers. comm., 8 March 2012)

Table 9 continued

Initiative	Purpose	Impact and progress
Residential Energy Efficiency Scheme (REES)	Establishes obligations on energy retailers (with 5000 or more customers) to provide energy audits and recommend energy-efficiency activities to South Australian households to reduce energy consumption. REES is given effect through Regulations made under the *Electricity Act 1996* and the *Gas Act 1997*. The objectives of the REES are to: • improve energy efficiency and reduce greenhouse gas emissions within the residential sector • help households prepare for likely energy price increases resulting from carbon pricing • reduce total energy cost for households, particularly low-income households	Targets for energy efficiency activities to reduce greenhouse gas emissions have been set. All targets were met in aggregate for the first stage of the scheme (2009–11), with 657 011 tonnes of CO_2-e of potential future energy-related greenhouse gas reduction over the lifetime of the activities (ESCOSA 2012). The second stage of the scheme (2012–14) has a target of 1 million tonnes of CO_2-e of lifetime energy-related greenhouse gas reduction. However, there is no obligation for householders to undertake the recommended activities
Various programs, including the Low Emission Vehicle Strategy, Sustainable Development and Climate Smart Precincts, Building Innovation Fund, Cool Roofs, and Mini Wind Turbine Trial		These initiatives are of a transformative nature and have the potential to substantially lower emissions in the longer term

CO_2-e = carbon dioxide equivalent; LULUCF = land use, land-use change and forestry

To date, the most effective initiative to reduce South Australia's greenhouse gas emissions has been the drive to increase renewable energy generation in the state. The *Climate Change and Greenhouse Emissions Reduction Act 2007* has a target for renewable electricity generated and consumed to comprise at least 20% of electricity generated and consumed in the state by 2014.

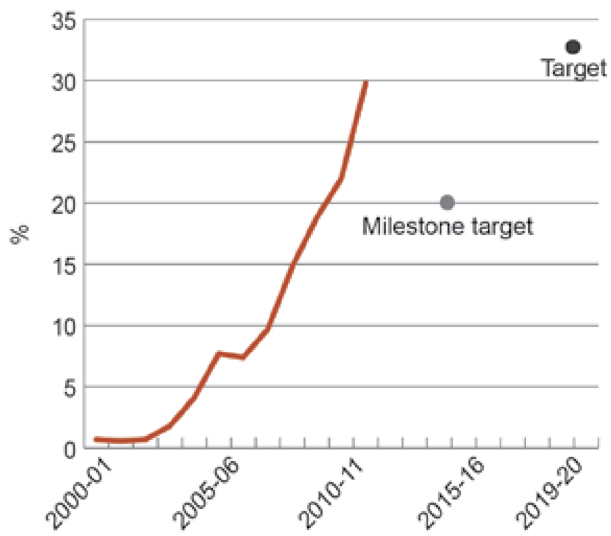
In 2010–11, renewable electricity provided 22% of the state's generation (Table 10; Figure 7), three years ahead of the 2014 target schedule. Wind generation capacity reached 1203 megawatts from 15 wind farms by the end of 2011 (South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy, pers. comm., 8 March 2012). For 2011–12, electricity from wind reached 26% of generation, and 2.4% is estimated to have come from roof-top solar photovoltaic systems (AEMO 2012). South Australia's success in this area is attributable not only to world-class renewable resources, but to the deliberate actions of the state government to tailor regulatory frameworks appropriately and provide investment clarity and certainty (Government of South Australia 2011a).

Table 10 Renewable electricity as a percentage of total South Australian generation

Year	2000–01	2001–02	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11
%	0.7	0.6	0.7	1.8	4.0	7.7	7.4	9.7	14.8	18.8	22.0

Solar installation, Adelaide Showground

Department of Manufacturing, Innovation, Trade, Resources and Energy (DMITRE)



Sources: South Australian Department of Environment, Water and Natural Resources; Australian Energy Market Operator (South Australian Supply and Demand Outlook), Electricity Supply Industry Planning Council (annual planning reports), ETSA Utilities (solar statistics for 2009–10), former Australian Government Department of Environment, Water, Heritage and the Arts (solar statistics from the Solar Homes and Communities Program)

Figure 7 Renewable electricity as a percentage of total South Australian generation

The 20% target established under the *Climate Change and Greenhouse Emissions Reduction Act 2007* has since been strengthened under this legislation and is reflected in South Australia's Strategic Plan (Government of South Australia 2011b). The Strategic Plan sets a further target to support the development of renewable energy so that it comprises 33% of the state's electricity generation by 2020.

In 2011, the South Australian Government recognised the need for continued state government intervention to achieve the 33% renewable energy target and outlined its plan in the strategy document *A renewable energy plan for South Australia*. This outlines the critical role of South Australia in providing complementary policy to support the Australian Government's renewable energy investment programs and policies. Specifically, the principal roles for the South Australian Government are:

- dissemination of detailed, timely and commercially relevant information to ensure that the investment market is fully informed of opportunities within the state
- provision of efficient regulation and a competitive government fee-charging regime
- intervention to address market failures created by specific regional circumstances
- leading by example to establish an environment that builds investor confidence in renewable energy
- acting early to position the state to benefit from imminent national policies and to better respond to cost impacts (Government of South Australia 2011a).

Many more high-quality wind resource sites exist in addition to those already developed. A number of further wind projects have been publicly announced, although none of these are yet under construction or committed to construction (AEMO 2011b). Significant potential geothermal prospects have been identified in South Australia (AEMO 2011a), and the state government continues to support geothermal research, exploration and proof-of-concept projects. Three of the most advanced Australian geothermal projects are located in South Australia: in the Cooper Basin, the northern Flinders Ranges and the Otway Basin. These sites are projected to supply energy to pilot electricity plants within 2–5 years (Betina Bendall, Principal Geologist, South Australian Department for Manufacturing, Innovation, Trade, Resources and Energy, pers. comm., 10 March 2012).

South Australia's Strategic Plan (Government of South Australia 2011b), contains a target to limit the carbon intensity of total South Australian electricity generation to 0.5 tonnes of CO_2-e per megawatt hour (CO_2-e/MWh) by 2020. South Australia's current electricity emissions intensity factor is 0.65 tonnes of CO_2-e/MWh, including both South Australian generation and imported electricity (Table 11). This falls to 0.6 tonnes of CO_2-e/MWh in 2010 if only South Australian grid generators are included.

Table 11 South Australian electricity emissions factors

	1990	1995	2000	2005	2006	2007	2008	2009	2010	Latest estimate
South Australian grid including imports (tonnes CO_2-e/MWh)	0.81	0.87	0.92	0.89	0.87	0.83	0.77	0.72	0.67	0.65
South Australian grid generators (tonnes CO_2-e/ MWh)	0.78			0.78	0.75	0.73	0.66	0.65	0.60	0.56

CO_2-e = carbon dioxide equivalent; MWh = megawatt–hours

Source: Australian Government Department of Climate Change and Energy Efficiency, National Greenhouse Accounts Factors (July 2012), Table 40: Scope 2 emissions factors

South Australia's Strategic Plan (Government of South Australia 2011b), contains a residential energy efficiency target to improve the energy efficiency of dwellings by 15% by 2020 (compared with 2003–04). This is through a number of state programs, such as the Residential Energy Efficiency Scheme (Table 6), 6-star energy efficiency requirements for new homes, managing energy use of air-conditioners and residential water heater requirements (Government of South Australia 2011c).

4.3 Adapting to climate change

Along with reducing emissions to limit the level of climate change, South Australia also aims to mitigate the impacts of climate change through planning and development.

Prospering in a changing climate—a climate change adaptation framework for South Australia (Government of South Australia 2010) was launched in August 2012. The framework aims to guide action in preparing for the impacts of climate change by government agencies, local government, non-government organisations, business and the community. It also aims to facilitate the development of more detailed adaptive strategies at regional, sectoral and statewide levels. A range of adaptation activity is under way across South Australia at a state government, local government and regional level. This includes the development of policies and plans that begin to address sea level rise, sustainable water supplies, natural resource management impacts, primary industry impacts and community health impacts. A wide range of research projects are informing adaptation responses for natural and human systems (DEWNR 2012).

Work is also taking place in particular sectors affected by climate change. For example, South Australia already has a comprehensive and integrated water planning system and expertise in water management technologies, which will form the basis for adaptation in the water sector. The South Australian State Emergency Service and key South Australian Government departments have developed an Extreme Heat Plan to ensure a coordinated approach to increasing community awareness, preparedness and response to extreme heat events (SA SES 2010).

5 What can we expect?

A global average temperature increase from pre-industrial levels of 4 °C is well outside the relatively stable temperature regimes that have allowed the development of modern civilisation, and that have probably prevailed for our species at all times in our history. Potential impacts of climate change range from highly disruptive to catastrophic. There is a risk that the climate system may reach a 'tipping point' at which a small additional change may trigger a large, abrupt response. These responses can be irreversible in a timeframe that is relevant to humans (Garnaut 2011, New et al. 2011).

In Australia, the effects of a 4 °C global average temperature rise would include:

- temperature increases of 3–5 °C in coastal areas and 4–6 °C inland
- increases in the occurrence of extremely high temperatures
- likely significant declines in annual rainfall in southern Australia
- increases in evaporation and drought
- an increase in extreme rainfall events, increasing the risk of flooding
- an increase in extreme fire weather
- sea level rise of up to 1.1 metres by 2100, increasing to more than 7 metres over subsequent centuries, even with no further warming
- substantial loss of marine and terrestrial ecosystems and biodiversity, with the resilience of many or most ecosystems being exceeded (Whetton et al. 2011).

The magnitude of future climate impacts will depend on what global effort is made this decade to substantially reduce greenhouse gas emissions, and the impact of inevitable change will depend on the preparations made now.

5.1 Reducing emissions

Effective global emissions reductions will require action on many fronts, including international agreements, economic reform, government regulation, investment in technological innovation and societal change. It will require the united efforts of government, industry and the public at large (Ackerman and Stanton 2011, CSIRO 2011).

Achieving deep cuts in Australia's greenhouse gas emissions will require a major alteration to public attitudes and understanding of climate change, to provide the incentive for cuts in personal energy demand and acceptance of low-emissions technologies, so that governments are empowered to rapidly transition Australia to a low-carbon economy (CSIRO 2011). Recent research indicates that, since the 1990s, there have been increases in public levels of uncertainty and diversity of opinion about the causes of climate change and the extent of the problem. There is also a perception of disagreement among scientists and a lack of confidence in the ability of science to predict the nature and effects of climate change (Ashworth et al. 2011, Washington and Cook 2011). Attitudes have also been affected by the bitterly partisan public policy debates associated with the carbon tax (Climate Institute 2012).

Although the Australian Government is now leading the domestic mitigation agenda, it recognises the important role of the states and territories in the national initiative, particularly in the promotion of renewable energy and energy efficiency, land-use planning and public transport (State of the Environment 2011 Committee 2011). Many emissions sources will not be impacted sufficiently or at all by a carbon price, and this is where state governments have a clear leadership role.

If South Australia is to play its part in the timely reduction of global emissions, only a government-wide, coordinated and concerted approach to mitigation will be successful in rapidly moving the state to a low-carbon economy. Some of the current abatement initiatives focus on improved efficiencies against a backdrop of population and economic growth endeavours, while other projects are of a demonstrative nature with potential abatement benefits to be realised well into the future.

With a natural endowment of renewable resources, South Australia is well placed to build on its success in attracting renewable energy investment, and delivering significant and timely greenhouse gas abatement. A low-carbon economy also provides hedging against carbon prices and a competitive advantage in a global carbon-sensitive market (Government of South Australia 2011a).

An extensive opportunity for wind generation has been identified in the Eyre Peninsula. With new transmission investment, this region is capable of meeting the state's entire average electricity needs in times of high wind (Baker and McKenzie et al. 2010). South Australia also has significant potential for geothermal energy, world-class solar electricity levels in the north of the state and wave energy resources (Figure 8). However, achievement of the 33% renewable energy target will require continued deliberate state government policy support in addition to the national effort, as competition for renewable energy investment intensifies (Government of South Australia 2011a).

A future pressure on the state's emissions is the expansion of mining activity, particularly at Olympic Dam. The proposed open-pit mine will increase production of copper, uranium oxide, gold and silver, with an associated estimated additional 4.7 Mt of CO_2-e per year emitted from electricity and diesel use at full production by around 2020. This equates to around 15% of the state's current emissions. In gaining approval for the project, BHP Billiton has committed to deep cuts in emissions by 2050, sourcing renewable energy for the desalination plant and constructing an onsite cogeneration plant.

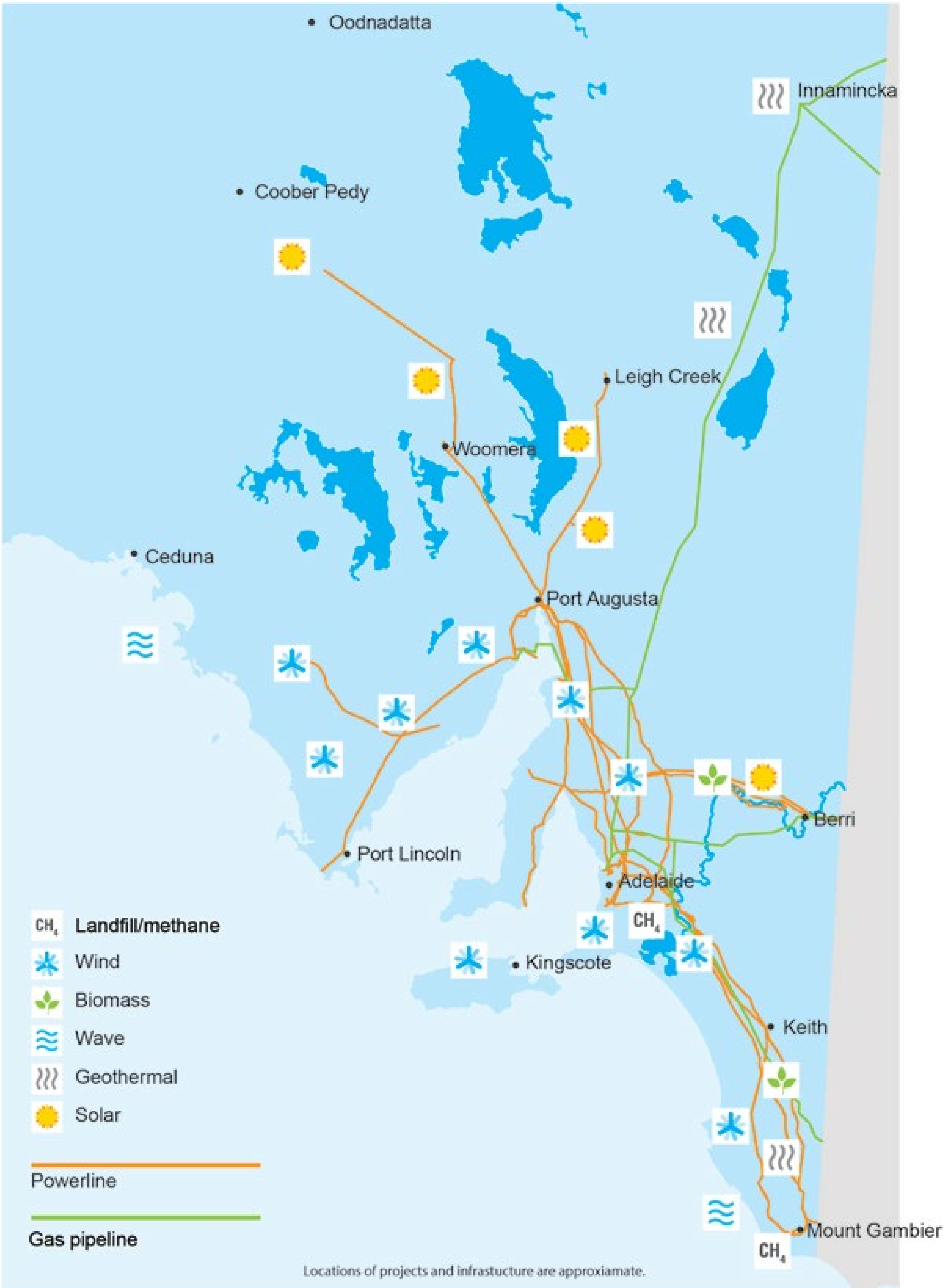
5.2 Adapting to unavoidable climate change

Future climate change impacts are unavoidable given existing greenhouse gases in the atmosphere and future emissions resulting from the world's slow mitigation response (CSIRO 2011). The latest scientific agreement is that we are heading for global warming of at least 2 °C—possibly 4 °C by 2070 (CSIRO 2011).

Adaptation policy needs to incorporate a wide range of possible futures. The extent and cost of the adaptation requirement will depend on how successful the world is in mitigating climate change (Garnaut 2011). Climate changes may move from incremental to transformative, requiring a complete transformation in many aspects of society in the more vulnerable regions of the world (New et al. 2011). The impacts on society associated with a 4 °C warming present great challenges for adaptation.

South Australia is highly vulnerable to projected climate change, and adaptation planning is important to reduce exposure and vulnerability, and increase resilience to potential adverse impacts. South Australia's key vulnerable areas are water supply, the natural environment, cities and infrastructure, the coastal zone, agriculture and human health. Climate impacts on other countries will affect South Australia's import and export markets. Adaptation planning will also enable the state to position itself to take advantage of potential opportunities in new markets (DCCEE 2012a, IPCC 2012).

The South Australian Government outlined the need to undertake adaptation planning in 2009 and has since developed *Prospering in a changing climate: a climate change adaptation framework for South Australia* (Government of South Australia 2010). The adaptation and preparation processes already started (see Section 4.3) are essential to ensure that we minimise the impacts of climate change on essential services, such as our primary industries and water supply. Adaptation considerations will need to be incorporated into all government policy and planning processes.



Source: Government of South Australia (2011a)

Figure 8 Potential zones for renewable energy, South Australia

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