Australia
State of the Environment 2016

Atmosphere

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Atmosphere

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Acknowledgement of Country

The authors acknowledge the traditional owners of Country throughout Australia,
and their continuing connection to land, sea and community;
and pay respect to them and their cultures,
and to their Elders both past and present.

Australian Government

Department of the Environment and Energy

Publication information

Citation

Keywood MD, Hibberd MF & Emmerson KM (2017). *Australia state of the environment 2016: atmosphere,* independent report to the Australian Government Minister for the Environment and Energy, Australian Government Department of the Environment and Energy, Canberra.

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Cover photo: Storm front at Cunninghams Gap, Queensland, by Ryan Francis

Editing, design and production: Biotext, Canberra

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Executive summary

Climate change is a global problem, and minimising its impact on the Australian environment will require coordinated international action by all countries. The Paris Agreement, to which 195 countries have agreed, aims to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 °C. Australia ratified the Paris Agreement in November 2016.

As its contribution to global efforts, the Australian Government has committed to reducing emissions to 26–28 per cent below 2005 levels by 2030. The energy sector continues to be the dominant source of Australia's greenhouse gas emissions, accounting for 76 per cent of net emissions in 2015. Australia's heavy reliance on fossil fuels as a primary energy source has resulted in Australia's per-person emissions of carbon dioxide in 2013 being close to twice the average of countries in the Organisation for Economic Co-operation and Development. Australian governments at all levels are acting to reduce net emissions through a range of mechanisms, including carbon pricing, land sector mitigation, renewable energy targets and energy efficiency programs. Emissions projections reported by the Australian Government in 2015 presented a significant downwards revision in the cumulative abatement task, suggesting that Australia is on track to meeting its 2020 emissions reduction target of 5 per cent of 2000 emissions. Of note is that many of the factors that have contributed to the significant downwards revision in the cumulative abatement task are likely to change (e.g. growing seasons may improve; commodity prices may increase). Hence, the cumulative abatement task may be revised upwards in later projections. In addition, the significant debate about whether the Emissions Reduction Fund will be as effective as proposed by the Australian Government contributes to uncertainty around the cumulative abatement task presented in 2016.

Climate change will result in location-specific vulnerabilities. People who are socially and economically disadvantaged are the most sensitive to climate change. As warming increases, Australia is forecast to experience:

- increased heatwaves, leading to increased bushfire incidence and health problems (heat stress)
- longer droughts, extending further geographically than they have done in the past
- flooding from more intense storm activity
- sea level rise, leading to coastal damage
- loss of ecosystems.

An understanding of the risks associated with Australia's climate will lead to improved action plans to adapt to the changes predicted to occur. Mitigation and adaptation are both essential for climate risk management at all scales. However, the success of climate-resilient pathways will be fundamentally linked to the effectiveness of climate change mitigation.

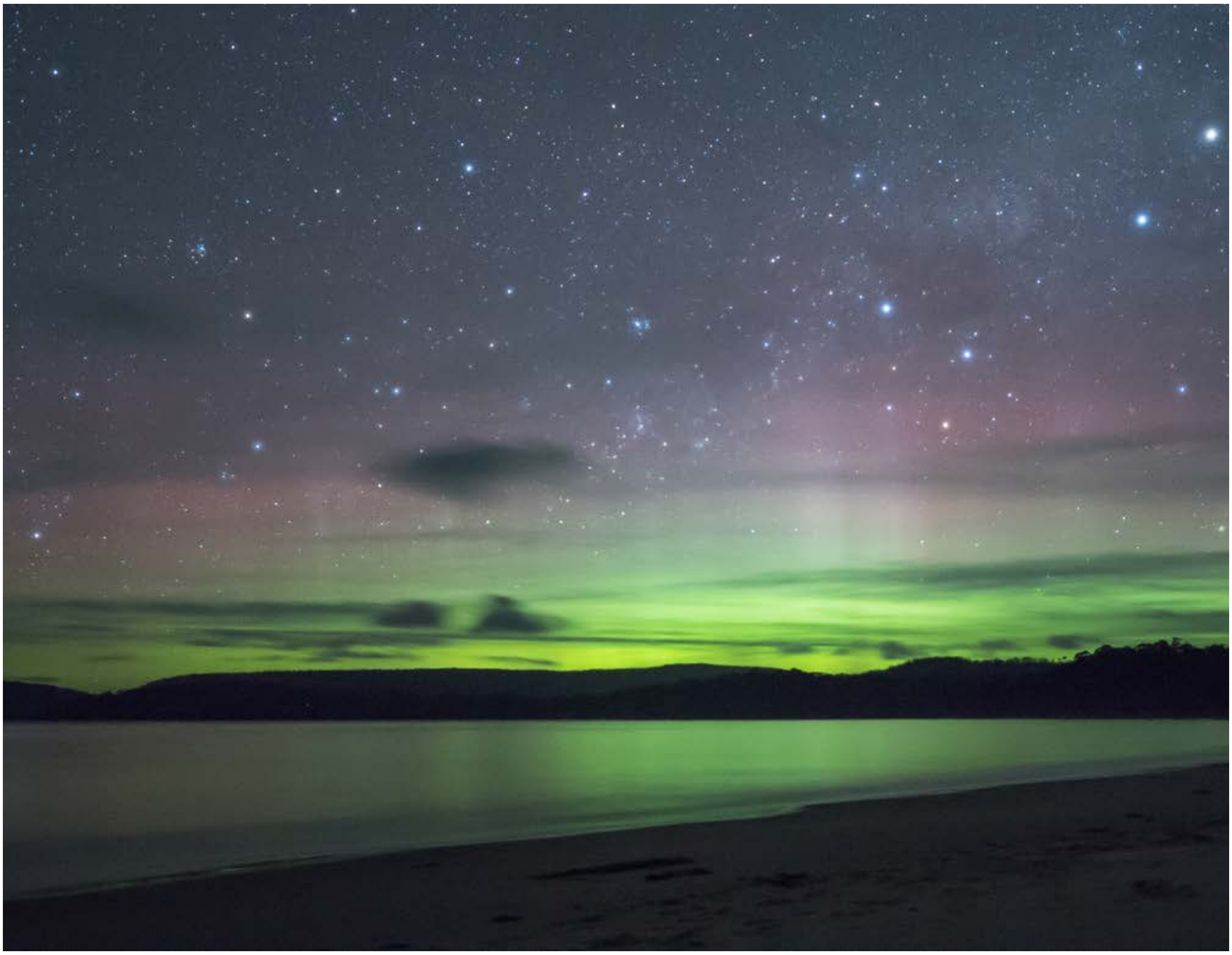
Human activity places significant pressure on ambient air quality through industrial emissions; vehicle and road traffic emissions; dust; and smoke from bushfires, prescribed burning and domestic wood heating. In urban centres, where air pollution is most prevalent, air quality is usually restored to acceptable levels once the immediate conditions change. However, human resilience to the effects of prolonged or recurring exposure to air pollutants is limited. Poor air quality is linked to respiratory and cardiovascular illnesses, and increased mortality.

Air quality in Australian urban centres is classified as either 'good' or 'very good'. All levels of government play a role in preventing or minimising air pollutant emissions, through such measures as national air quality standards, and emissions standards for vehicles and industry. Levels of lead and nitrogen dioxide have declined markedly in all centres in recent decades. Ozone levels have remained stable since the 2011 state of the environment report.

Levels of particulate matter less than 10 microns in diameter (PM_{10}) now rarely exceed the national standard. However, the advisory limit for $PM_{2.5}$ (particles less than 2.5 microns in diameter) is frequently exceeded because of extreme events such as bushfires, smog and dust storms.

The outlook for Australia's urban air quality is generally good. Motor vehicles are the main diffuse source of air pollution in urban areas. Although the size of the Australian fleet is continuing to grow, emissions are expected to continue to decline during the next decade as a result of tighter national fuel standards and mandating of improved emission-control technologies. However, although levels of carbon monoxide, lead, nitrogen dioxide and sulfur dioxide have decreased in the past 10 years, ozone and particle levels have not declined. Moreover, climate change is expected to increase the potential for ozone, bushfire and smoke pollution. Ongoing effort will be required to secure past gains and achieve further improvements. Prospects for achieving reductions in levels of ozone and particles will be influenced by several factors, most notably:

- vehicle technology
- control of pollution from domestic wood heaters
- the extent of ongoing urban sprawl
- the availability of reliable public transport
- the impact of climate change on urban airsheds.



Aurora australis from Gilhams Beach, Tasmania

Photo by Megan Watson

Key findings

Key finding	Explanatory text
'Human influence on the climate system is clear'	The Intergovernmental Panel on Climate Change (IPCC) made this statement in its most recent report (Stocker et al. 2013a). The IPCC's role is to review, assess and synthesise the latest information on climate change. Concentrations of carbon dioxide (CO_2) in the atmosphere have increased at the rate of 2.3 parts per million per year (about 0.6 per cent per year) since 2000. Citing more than 9200 scientific publications, with contributions from more than 600 authors, the 5th IPCC assessment confirmed (with between 95 and 100 per cent certainty) that humans have been the dominant cause of increases in greenhouse gas concentrations since the 1950s.
Emissions continue to contribute to climate change	Australia's emissions of CO_2 per person in 2013 were nearly twice the average of countries in the Organisation for Economic Co-operation and Development, reflecting Australia's heavy reliance on fossil fuels as a primary energy source, particularly the use of coal in the production of electricity. The recent Paris Agreement aims to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels, and pursue efforts to limit the temperature increase to 1.5 °C. The Australian Government ratified the Paris Agreement in November 2016 and has committed to reducing emissions to 26–28 per cent below 2005 levels by 2030. Between 1990 and 2015, Australia's emissions decreased by 27 per cent.
The world is warming	The year 2015 was the warmest on record for the globe. The shift towards higher temperatures has been associated with regional increases in the frequency, duration and intensity of extreme heatwaves.
Australia is warming	Australian average temperatures have increased by 1 °C in the past 100 years, especially since the 1950s. The year 2013 was Australia's warmest year on record, and the springs of 2013, 2014 and 2015 were Australia's 3 warmest springs on record. Without mitigation, a surface temperature increase of 3.7–4.8 °C above 1850–1900 temperatures is projected for Australia.
Australia has a long-term trend of declining rainfall	Australian rainfall has been largely variable in the past 100 years, particularly the past 40 years. The millennium drought (2000–10) was followed by the wettest 2-year period on record (2010 and 2011). After that, drought re-emerged across large areas of southern and eastern Australia, including Queensland. Long-term rainfall deficiencies across Victoria, Tasmania, south-eastern South Australia and south-western Western Australia are overlaid on a long-term trend of declining rainfall in autumn and winter, or the first half of the southern wet season, in parts of south-eastern and south-western Australia.

Key finding	Explanatory text
The oceans have somewhat mitigated the effects of emissions	The oceans absorb CO_2 and heat, and thus limit the rate and immediate extent of changes in climate. In recent decades, the oceans have taken up around 25 per cent of the annual anthropogenic (human) CO_2 emissions. However, the capacity of the oceans to absorb CO_2 is limited, because this absorption makes the oceans more acidic.
Climate change will affect Australian regions differently	Climate change will result in location-specific vulnerabilities. Australia is predicted to experience increased heatwaves, leading to increased bushfire incidence and health problems (heat stress); longer droughts, extending further geographically; flooding from more intense storm activity; sea level rise, leading to coastal damage; and loss of ecosystems. The 2016 bleaching of the Great Barrier Reef demonstrates how vulnerable Australian ecosystems are to climate change.
Climate-resilient pathways are needed to protect society	Resilience of a society to climate change is dependent on the sensitivity of the society to change and its capacity to adapt to change. People who are socially and economically disadvantaged are the most sensitive to climate change. Resilience through adaptation may involve significant transformations in political, economic and socio-technical systems. It is important that vulnerabilities in social resilience are reflected in national and international policies aimed at adapting to climate change.
Air pollution can be natural or anthropogenic	Sources of air pollution include industrial emissions; vehicle and road traffic emissions; dust; and smoke from domestic wood heaters, prescribed burning and bushfires.
Population and climate change are the biggest pressures on air quality	The population of Australia's major cities will continue to grow, meaning that human activity, and consequent power and transport requirements, will increase. This will increase air pollution. Climate change also plays a role in air pollution. The increasing prevalence of extreme heatwaves changes the chemical reactivity of the atmosphere, promoting the formation of photochemical smog; increasing numbers of fire days will increase smoke production; an increase in heatwaves will encourage people to use cooling systems, which will place pressure on power requirements and increase emissions to the atmosphere; and reduced rainfall and drought could promote dust events.
Australia has national air quality standards	The National Environment Protection Measure for Ambient Air Quality (Air NEPM), revised in 2016, sets national standards for ambient air quality. The measure is designed for the protection of human health and mandates a consistent approach to air quality monitoring, which has been applied by all states and territories. The Air NEPM is supported by national emissions standards for new vehicles and by fuel quality standards.

Key finding	Explanatory text
Air pollution is a significant health hazard	Urban air quality is a significant cause of death and illness. There is a statistically significant relationship between higher levels of fine particles and respiratory and cardiovascular disease, and increased mortality. In 2013, the International Agency for Research on Cancer classified outdoor air pollution as a human carcinogen. There is clear evidence that even short periods of poor urban air quality have serious adverse impacts on human health. A limitation of the standards-based approach is that there is now strong evidence that many pollutants do not have a recognised threshold below which there are no adverse health effects. Thus, the 2016 update of the Air NEPM includes a new requirement to report on a population exposure metric for fine particulate matter ($PM_{2.5}$) each year, starting in 2018. This will provide data to assess changes in population exposure and better target control measures.
Air quality in Australian cities is generally good	Air quality in Australian urban centres is classified as either 'good' or 'very good'. However, although levels of carbon monoxide, lead, nitrogen dioxide, coarse particulate matter (PM_{10}) and sulfur dioxide have decreased in the past 10 years, ozone and fine particle ($PM_{2.5}$) levels have not declined, and ongoing effort will be required to secure past gains and achieve further improvements.
Reducing fine particles in the atmosphere is our next major challenge	Particulate matter has been identified as a significant hazard to human health. Levels of PM_{10} now rarely exceed the national standard. However, the standard for fine particles ($PM_{2.5}$)—which, until 2016, was an advisory limit only—is frequently exceeded because of events such as bushfires, smog, dust storms and use of domestic wood heaters. $PM_{2.5}$ can be transported further and persist for longer in the atmosphere than PM_{10}, and can also be breathed deeper into the lungs, which can cause more negative health effects. We do not fully understand all the processes that lead to $PM_{2.5}$ formation, which is a challenge for design of effective and efficient control measures.

Approach

In this report, we assess the state of Australia's atmosphere through an assessment of Australia's climate and the effects of climate change, and ambient air quality.

The approach adopted in this report follows that outlined in the *Approach* report (i.e. the assessment of pressures, state, effectiveness of management, resilience, risk and outlook).

Both climate and air quality are influenced by the emission of pollutants to the atmosphere from anthropogenic (human) activities and natural processes. The state and trends of the climate and air quality result from the response of the atmosphere to the presence of these pollutants.

The pressures that influence climate and air quality, and the trends for parameters reported in the 2011 state of the environment report (SoE 2011; State of the Environment 2011 Committee 2011) are again considered in 2016, and updated with data and information that have become available in the past 5 years. Air quality is quantified using the 'report card' methodology presented in SoE 2011.

This theme report discusses the management actions undertaken to reduce emissions and thus mitigate the impacts of these pollutants, as well as the resilience of the climate system and urban airsheds to recover from the disturbances caused by these emissions. The resilience of society to adapt to climate change and impaired air quality, and the risks projected to arise from further change are also presented.

The sections on effectiveness of management examine actions—from global to local—for both climate and air quality. The resilience sections have been updated to include the resilience of physical systems (climate and polluted airsheds) and of society to climate change (via adaptation) and to degraded air quality. The assessment summaries in all sections are based on peer-reviewed assessments and expert opinion.

We have striven, where possible, to make SoE 2016 an update of SoE 2011, so that much of the structure and content are comparable between the 2 reports.

However, a few changes have been made. Stratospheric ozone, which was a component of the air quality section in SoE 2011, is limited to a discussion of stratospheric ozone across Australia, and stratospheric ozone related to the Antarctic ozone hole is discussed in detail in the *Antarctic environment* report. Similarly, indoor air quality, which was discussed in the 'Atmosphere' chapter in SoE 2011, is discussed in the *Built environment* report in SoE 2016.

Climate

Introduction

Australia has always been a land of extremes. In a single year, we can experience heatwaves, floods, fires, cyclones and drought.

Australia's highly variable climate is influenced year to year by large-scale drivers in the atmosphere and ocean, such as the El Niño–Southern Oscillation (ENSO). This variability is now occurring against a background trend of increasing mean temperatures because of anthropogenic climate change.

Since 1950, the number of heatwave days each year has been increasing in many urban centres and across Australia as a whole (Perkins & Alexander 2013, Steffen et al. 2014); 2013 was the hottest year since temperature records began in 1990. Since the 1970s, the increases in fire-danger weather have been significant across south-eastern Australia (Clarke et al. 2013, CSIRO & BoM 2014). The millennium drought, which saw much of southern Australia experience dry conditions between 2000 and 2010 (although in some areas the drought began as early as 1997 and ended as late as 2012), was followed by heavy rainfall (and associated flooding) across much of Australia during 2010 and 2011 (BoM 2015).

As the Australian climate continues to warm, the droughts and flooding rains of Dorothea Mackellar's poetic description of our sunburnt country are projected to become more severe. Climate change could be considered as the greatest environmental challenge facing Australia.

Climate: 2011–16 in context

As reported in SoE 2011, climate change continues to be a global problem. A major development since the 2011 report has been international cooperation to address the global issue, with 195 countries, including Australia, agreeing to the Paris Agreement, which aims to limit the increase in global temperatures to 2 °C above pre-industrial levels. International climate science has also advanced significantly. The Intergovernmental Panel on Climate Change, in its Fifth Assessment Report, confirmed (with between 95 and 100 per cent certainty) that humans have been the dominant cause of increases in greenhouse gas concentrations since the 1950s (Stocker et al. 2013a).

As in SoE 2011, Australia's greenhouse gas (GHG) emissions per person remain the largest of any country in the Organisation for Economic Co-operation and Development (OECD). However, emissions per person have decreased from 24.1 tonnes in 2011 to 22.2 tonnes in 2015. The energy sector continues to dominate GHG emissions, increasing from 74 per cent of net emissions in SoE 2011 to 76 per cent in 2015.

Since SoE 2011, the globe has experienced the hottest year on record (2015), and Australia has experienced its hottest year (2013). Since the 2011 La Niña that helped break the millennium drought, drought has re-emerged across large parts of Australia, especially western Queensland, northern New South Wales and western Victoria. The 2015 El Niño was associated with below average rainfall across large areas of eastern Australia.

Australian governments have continued to implement policies to reduce GHG emissions, and, in the 5 years since SoE 2011, 2 major federal programs have been established. In 2012, a cap-and-trade emissions trading scheme started. This included a carbon price and the Carbon Farming Initiative, which provided incentives to reduce emissions in the land sector. This was repealed in 2014 and replaced with the Australian Government's Direct Action Plan, including the Emissions Reduction Fund, which continues to operate.

The climate change projections for Australia, which model how Australia's climate is likely to evolve during the next century, are also new in SoE 2016. These projections suggest that mean temperatures and extreme temperatures are likely to increase, with more hot days and fewer cold days. Increased risk of heatwaves will lead to increased risk of wildfire incidence and health problems (heat stress). Other risks are longer droughts with greater geographic coverage, flooding from more intense storm activity, sea level rise leading to coastal damage, and loss of ecosystems.

Pressures
affecting Australia's climate

At a glance

Greenhouse gases (GHGs)—carbon dioxide (CO_2), methane, short-lived tropospheric and stratospheric ozone, nitrous oxide and synthetic GHGs—together with water vapour, and natural and industrial aerosols, influence Earth's energy balance. Human activity, primarily the burning of fossil fuels during the past 250 years, has caused well-quantified increases in the concentrations of GHGs in the atmosphere, resulting in significant increases in positive radiative forcing, which has a warming effect on climate. CO_2 levels in our atmosphere have increased by 43 per cent from pre-industrial (1750) levels, and methane levels have increased by 152 per cent. The contributions of CO_2 and methane to radiative forcing have increased since 1995.

Australia's emissions of CO_2 per person in 2013 were nearly twice the average of countries in the Organisation for Economic Co-operation and Development. This reflects Australia's heavy reliance on fossil fuels as a primary energy source and, particularly, the role of coal in the production of electricity. The energy sector continues to be the dominant source of Australia's GHG emissions, accounting for 76 per cent of net emissions in 2015. Within the energy sector, 52 per cent of emissions arise from electricity generation and 17 per cent from transport. The energy sector contributed 93.9 per cent of CO_2 emissions in the 2015 inventory, whereas the agriculture sector contributed 59.3 per cent of methane emissions and 72 per cent of nitrous oxide emissions.

Between 1990 and 2015, Australia's GHG emissions decreased by 27 per cent, and, in 2012, Australia met its commitments under the Kyoto Protocol by limiting increases in net GHG emissions to 103 per cent of its 1990 levels from 2008 to 2012. However, climate projections suggest that GHG emissions will continue to put pressure on our climate.

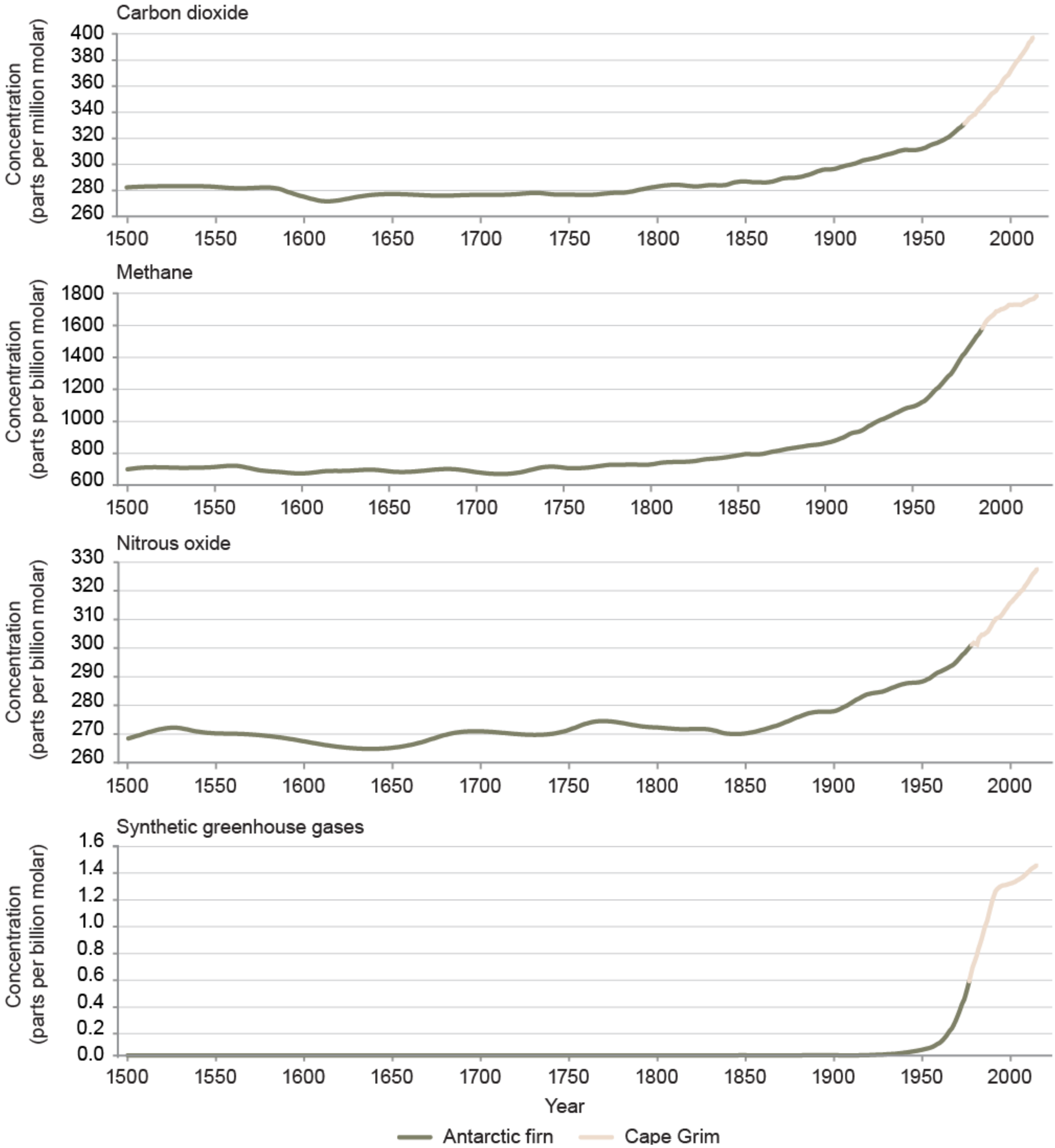
> *Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system. The evidence for human influence has grown since IPCC AR4 2007. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.* (Stocker et al. 2013a)

The energy balance of Earth's atmosphere is influenced by the presence of trace levels of GHGs, including carbon dioxide (CO_2), methane, short-lived tropospheric and stratospheric ozone, nitrous oxide and the synthetic GHGs (e.g. chlorofluorocarbons—CFCs, and hydrofluorocarbons—HFCs). Water vapour (a major GHG), and natural and industrial aerosols are also important in the atmospheric energy balance, as are clouds and the level of incoming solar radiation. The effect of climate change 'drivers' such as solar radiation, GHGs, aerosols and surface albedo (reflectivity) on the energy balance is termed 'radiative forcing' (see Box ATM1).

Increases in greenhouse gases

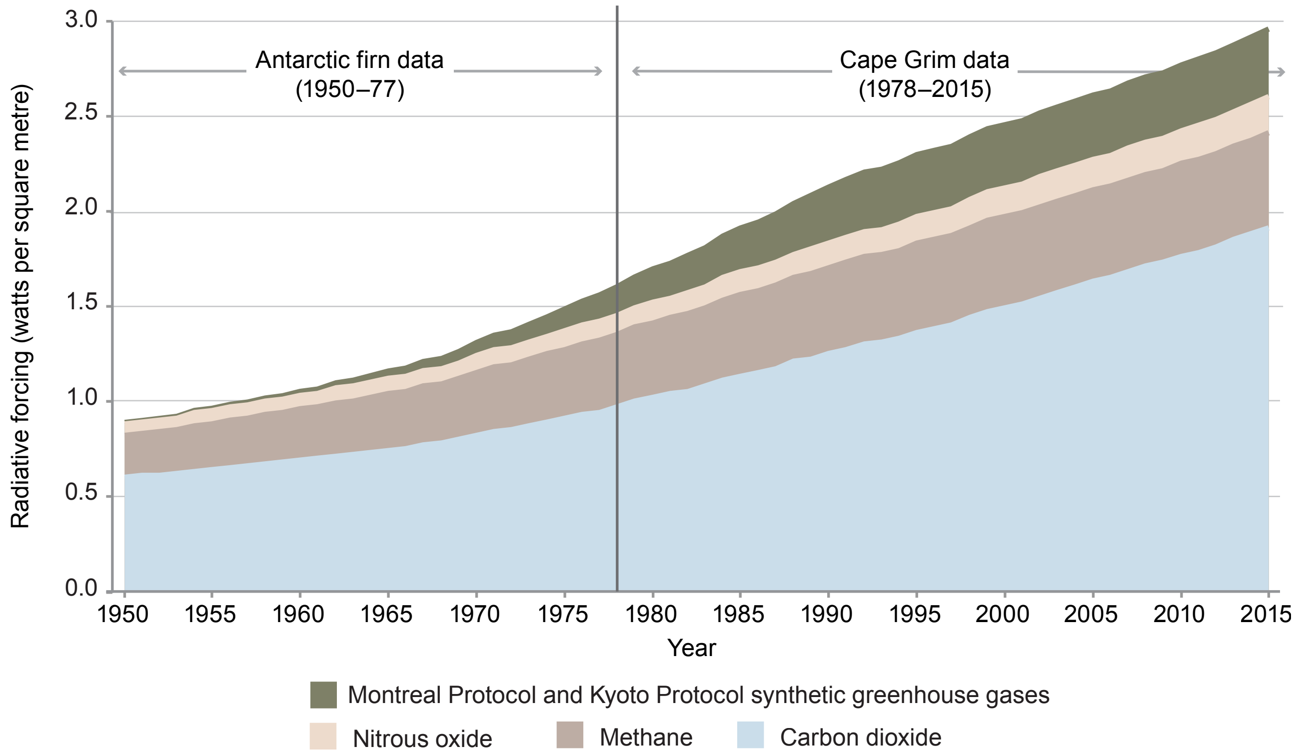
Human activity, primarily the burning of fossil fuels during the past 250 years, has caused well-quantified increases in the concentrations of GHGs in the atmosphere (Figure ATM1). This has resulted in significant increases in positive radiative forcing, which has a warming effect on the climate (Figure ATM2).

The CSIRO global GHG-observing network recorded a global CO_2 atmospheric concentration of 399.5 parts per million (ppm) for 2015. This represents an increase of 43 per cent from pre-industrial (1750) levels of 278 ppm, determined using data obtained from air extracted from ice cores (Etheridge et al. 1996, Hartmann et al. 2013).



Source: Observed by CSIRO in the atmosphere at Cape Grim, Tasmania (41°S) (data available from the World Data Centre for Greenhouse Gases), and from air extracted from Antarctic firn and ice cores (MacFarling Meure et al. 2006; data available from the World Data Centre for Paleoclimatology)

Figure ATM1 Annual mean concentrations of greenhouse gases (carbon dioxide, methane, nitrous oxide and synthetic greenhouse gases) observed at Cape Grim, Tasmania, and from air extracted from Antarctic firn and ice cores, 1500–2015



Note: Calculated from the concentration data in Figure ATM1 and radiative efficiencies (W/m²/ppb) from Myhre et al. (2013), Chapter 8. Montreal Protocol synthetic greenhouse gases (GHGs) include chlorofluorocarbons, hydrochlorofluorocarbons; Kyoto Protocol synthetic GHGs include hydrofluorocarbons, perfluorinated compounds and sulfur hexafluoride.

Figure ATM2 Radiative forcing as a result of long-lived greenhouse gases measured by CSIRO in the Southern Hemisphere

The global growth rate of CO_2 in the atmosphere is increasing: in the 1990s, it averaged 1.5 ppm per year; in the 2000s, it averaged 1.9 ppm per year; and, in the 2010s (to 2015), it averaged 2.3 ppm per year. This increase is largely because of increasing consumption of fossil fuels (coal, oil, gas) (Raupach & Fraser 2011, CSIRO unpublished data). The concentration measured at the Cape Grim Baseline Monitoring Station reached 400 ppm in May 2016.

CSIRO observations show that the global average methane concentration in 2015 was 1834 parts per billion (ppb), which is an increase of 154 per cent above the estimated pre-industrial level of 722 ppb (Etheridge et al. 1998, Hartmann et al. 2013). The global methane growth rate slowed in the 2000s (2.3 ppb per year) compared with the 1990s (4.9 ppb per year) (Raupach & Fraser 2011, CSIRO unpublished data), likely because of reduced emissions from global natural gas production and distribution. However, it increased again in the 2010s (7.8 ppb per year), possibly because of the increased global use of natural gas, and increased tropical and Arctic wetland emissions (Hartmann et al. 2013).

CSIRO observations show that global nitrous oxide levels in 2015 were 328 ppb, an increase of 21 per cent from the pre-industrial level of 270 ppb (Hartmann et al. 2013, CSIRO unpublished data). The global nitrous oxide growth rate was relatively constant in the 1990s (0.72 ppb per year) and the 2000s (0.77 ppb per year), but has increased significantly in the 2010s (0.95 ppb per year) (Raupach & Fraser 2011, CSIRO unpublished data). Increased use of nitrogenous fertilisers in global agriculture is the main cause of the increase in nitrous oxide (Park et al. 2012, Hartmann et al. 2013).

Several synthetic GHGs, including fluorinated GHGs—such as CFCs, HFCs, perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6)—are emitted from a range of industrial processes, and from business and domestic use[1] (Raupach & Fraser 2011). Although these gases are present in the atmosphere in only trace amounts, they are long-lived and have global warming potentials (measured in watts per square metre per ppb) that are thousands of times that of CO_2 when assessed on a 100-year timescale (Myhre et al. 2013, Rigby et al. 2014). They can therefore contribute significantly to global warming in the medium to long term, and are included in the set of synthetic GHGs (HFCs, PFCs, SF_6) covered by Annex A of the Kyoto Protocol. The production and consumption (and hence emissions) of CFCs, other ozone depleting substances and, recently (2016), HFCs are covered by the Montreal Protocol on Substances that Deplete the Ozone Layer and its subsequent amendments (see Box ATM2).

Of the total global radiative forcing because of long-lived GHGs:

- CO_2 contributed 64 per cent in 2014, compared with 59 per cent in 1995
- methane contributed 17 per cent in 2014, compared with 21 per cent in 1995
- fluorinated synthetic GHGs contributed 12 per cent in 2014, compared with 14 per cent in 1995
- nitrous oxide contributed 6 per cent in 2014 and 1995.

The baseline A1 scenario of the *Scientific assessment of ozone depletion: 2010* (Montzka et al. 2011) represents the 'best guess' for future abundances of CFCs, HFCs, PFCs and SF_6 in different Representative Concentration Pathways (RCPs). RCPs are 4 GHG concentration trajectories (RCP2.6, RCP4.5, RCP6 and RCP8.5) adopted by the Intergovernmental Panel on Climate Change (IPCC) for its Fifth Assessment Report (AR5) in 2014, which describe the radiative forcing values in the year 2100 relative to pre-industrial values.

In the A1 scenario, the synthetic GHG contribution to global radiative forcing will decrease to 6 per cent for RCP4.5 and to 8 per cent for RCP2.6 by 2100 (Prather et al. 2013), largely reflecting the gradual decline of CFCs in the atmosphere and increasing levels of HFCs through to 2100.

1 There is a natural background concentration of 0.034 ppb of tetrafluoromethane, a PFC (Harnisch et al. 1996)

Effects of increased greenhouse gases

The growing concentrations of human-generated GHGs have resulted in an increased absorption, largely in the lower atmosphere, of the heat radiated from Earth's surface, causing an increase in the global (land and ocean) mean surface temperature of 0.85 ± 0.20 °C from 1880 to 2012 (Stocker et al. 2013a)—a long-term average increase of 0.06–0.07 °C per decade. However, this rise did not occur evenly across the century—for example, average global temperatures did not increase between 1880 and 1910, or between 1940 and 1970.

From 1998 to 2012, global temperatures increased by 0.05 °C per decade, which is similar to the long-term trend, but less than the rate of increase from 1951 to 2012 (0.12 °C per decade). Because of natural variability, trends based on short records are very sensitive to the beginning and end dates, and do not, in general, reflect long-term climate trends (Stocker et al. 2013a). The year 1998 was a strong El Niño year with, at that time, record high global average temperatures (0.1–0.2 °C above 1990–97 temperatures). Thus, decadal or longer temperature trends commencing in 1998 are seemingly suppressed.

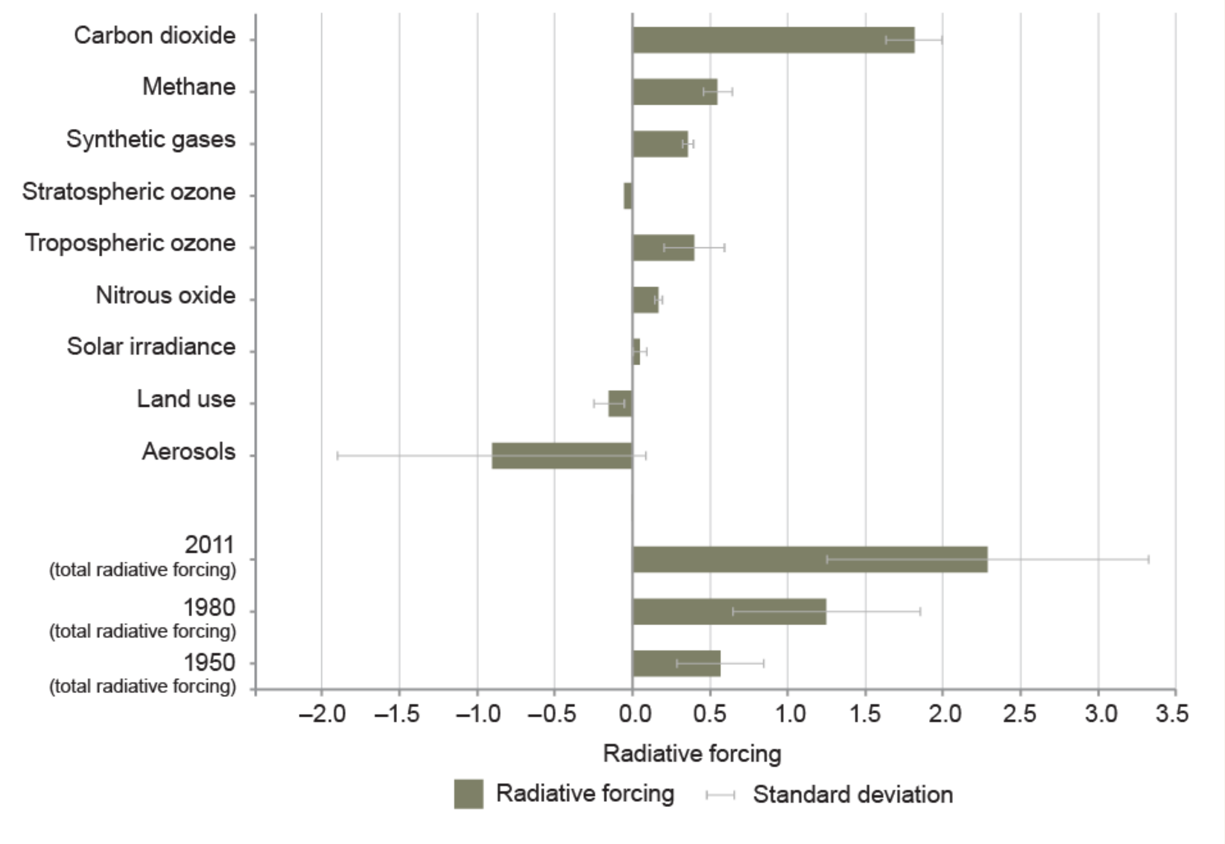
The so-called hiatus in global mean surface warming since 1998 was discussed extensively in AR5. Hiatus periods of 10–15 years can arise as a manifestation of internal variability. The relative heat accumulations by the atmosphere and the oceans across short timeframes are likely to be strongly influenced by internal variability of the atmosphere–ocean system. During 1998–2012, the overall climate system, including the ocean below a depth of 700 metres, has continued to accumulate heat and the sea level has continued to rise, consistent with the observed ocean heating and glacial melting.

Each of 2005, 2010, 2013, 2014 and 2015 (a strong El Niño year) set record high annual average global temperatures, showing that the long-term global temperature increase is continuing. The decade 2000 to 2010 has been the warmest decade in the instrumental record.

Box ATM1 Radiative forcing

Radiative forcing is a measure of the balance between the amount of energy (from sunlight) absorbed by Earth and the amount radiated back to space, quantified by the change in energy fluxes at the top of the atmosphere. Positive forcing leads to surface warming; negative forcing leads to surface cooling. Radiative forcing is affected by changes in drivers such as solar radiation, greenhouse gases (GHGs), aerosols and surface albedo (reflectivity). The level and direction of radiative forcing are estimated based on observations of radiation, surface albedo, and the concentrations and radiative properties of GHGs and aerosols.

Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change are shown in Figure ATM3. The net forcing is positive for GHGs as a whole, and negative for aerosols; however, considerable uncertainty exists about the magnitude of forcing from aerosols. The increase in solar radiation has caused a small, positive forcing since the start of the industrial era. Increased surface albedo because of land-use change caused a negative forcing across the same timeframe (Myhre et al. 2013).



Note: The synthetics are predominantly chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, perfluorinated compounds and sulfur hexafluoride. The best estimates of the net radiative forcing are shown as bars with uncertainty intervals; uncertainties are derived from a combination of confidence level (qualitative) and statistical probabilistic uncertainty (quantitative). Total anthropogenic radiative forcing is provided for 3 years (1950, 1980, 2011).
Source: Adapted from Myhre et al. (2013)

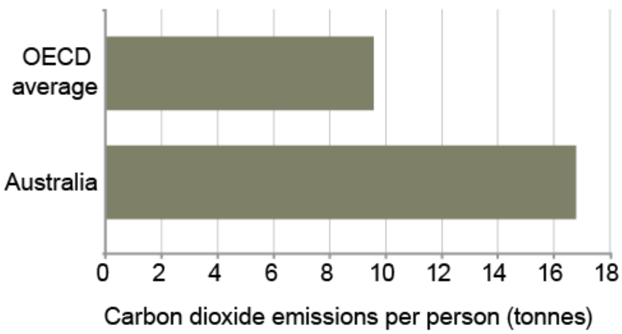
Figure ATM3 Radiative forcing in 2011 relative to 1750, and aggregated uncertainties for the main drivers of climate change

Australia's emissions in context

Although Australia's emissions in 2015 of 541 megatonnes of carbon dioxide equivalent[2] ($MtCO_2$-e) appear small alongside the most recent estimates from major emitters such as China (10,756 $MtCO_2$-e; 2010 estimate; UN Climate Change Secretariat 2015) and the United States (5791 $MtCO_2$-e; 2013 estimate), they are not insignificant, being on par with countries such as the United Kingdom (570 $MtCO_2$-e).

In addition, Australia's emissions are some of the most 'intense' in the world. Two measures of the emissions intensity of a country are comparison of emissions levels with population (per-person emissions) and comparison of emissions levels with the economy (per dollar of gross domestic product—GDP).

Per person, Australia's CO2 emissions in 2013 were the second largest of countries in the OECD—16.8 tonnes, which is 75 per cent higher than the OECD average of 9.6 tonnes (Figure ATM4).



Source: OECD (2015)

Figure ATM4 Carbon dioxide emissions per person, 2013

Box ATM2 Stratospheric ozone

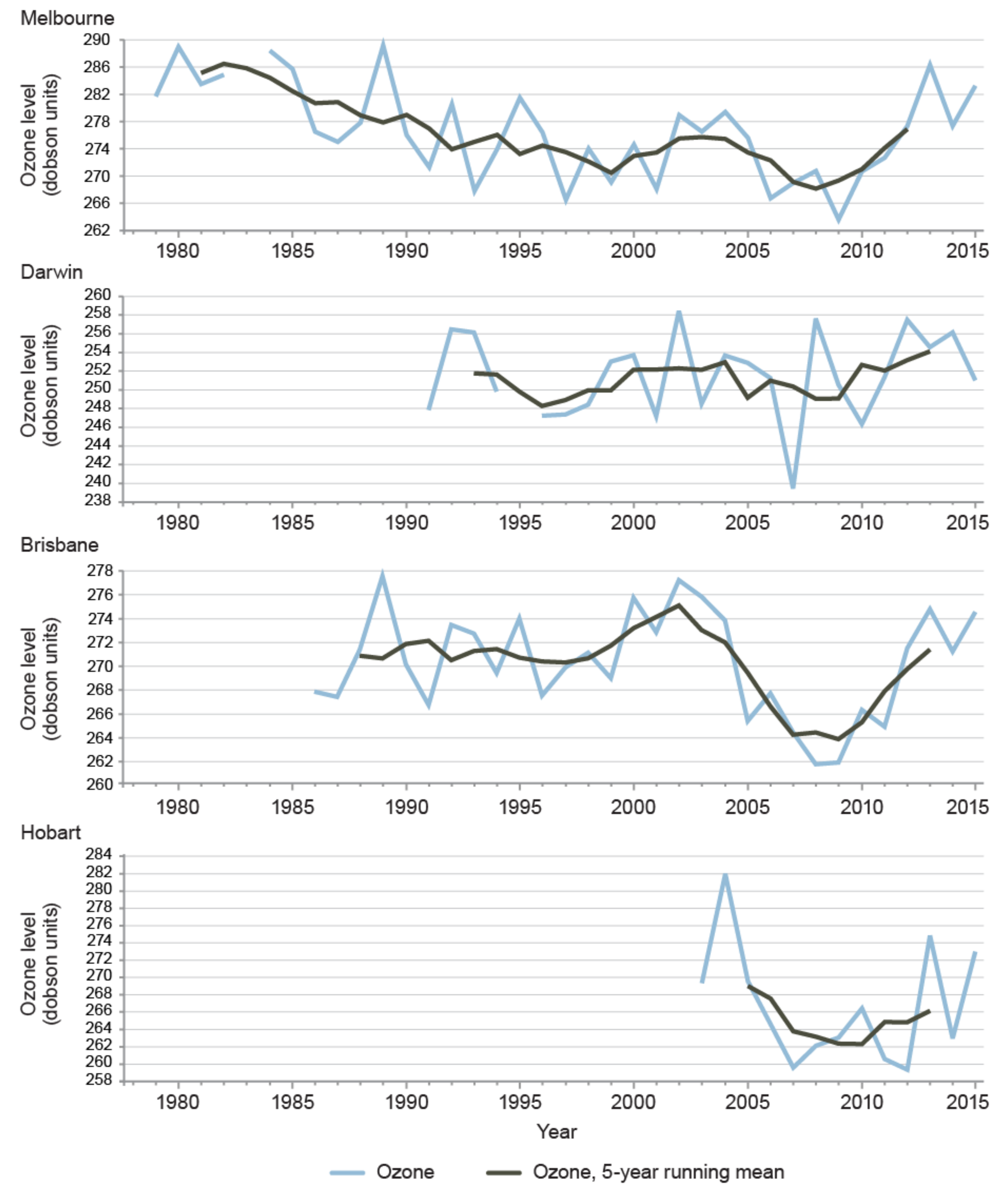
The stratosphere is the layer of the atmosphere that begins at an altitude of around 10 kilometres. The stratosphere contains about 90 per cent of the ozone in the atmosphere, which helps to make Earth inhabitable by absorbing a large proportion of incoming solar ultraviolet (UV) radiation before it reaches Earth's surface. UV radiation is harmful to a range of biological systems, including human health. It damages cells, and causes sunburn and premature skin ageing in low doses. At higher levels, it can cause skin cancer and suppress the immune system. Note that although stratospheric ozone protects human health, ozone near the ground, where it can be breathed in, is a pollutant and harmful to health. (See Ozone for further discussion of ozone as a pollutant.)

The stratospheric ozone layer was threatened by human-produced ozone depleting substances (ODSs), which were widely used in refrigerators, air-conditioners, fire extinguishers and electronic equipment; as solvents for cleaning (including dry-cleaning); and as agricultural fumigants. These substances contain chlorine and bromine atoms, which are released over time when ODSs break down and then react with ozone molecules to break them up. This has led to a reduction in stratospheric ozone in the mid-latitudes and a particularly severe reduction over Antarctica, known as the ozone hole (described in the *Antarctic environment* report). Since peaking in the 1990s, the atmospheric abundance of nearly all ODSs that are controlled under the Montreal Protocol has declined. However, these substances are long-lived in the atmosphere and many are also powerful greenhouse gases.

Figure ATM5 shows total column ozone levels above Melbourne, Darwin, Brisbane and Hobart for January each year from 1979 to 2015, where data are available. The dark line shows a 5-year running mean. Although considerable year-to-year variability is evident, such as the influence of the 11-year solar cycle (which peaked around 1980, 1991, 2002 and 2013), the decreasing trend seen in the 1980s and the first half of the 1990s indicates recovery of stratospheric ozone levels, as actions under the Montreal Protocol have become effective.

2 Carbon dioxide equivalent (CO_2-e) is a term for describing different GHGs using a common unit. For any quantity and type of GHG, CO_2-e signifies the amount of carbon dioxide that would have the equivalent global warming impact.

Box ATM2 (continued)



Source: Matt Tully, Bureau of Meteorology

Figure ATM5 Column ozone levels above Melbourne, Darwin, Brisbane and Hobart for January each year, 1979–2015

Australia's relatively high level of emissions per person reflects the nation's heavy reliance on fossil fuels as a primary energy source and, in particular, the dominant role of coal (an emissions-intensive fuel) in the production of electricity (Figure ATM6).

Australia's CO_2 emissions were also the second largest of OECD countries in 2013 per US$1000 of GDP—0.43 tonnes, which is 1.4 times the OECD average of 0.30 tonnes (Figure ATM7).

Despite these high rankings, Australia's emissions intensity decreased between 1990 and 2015. Since 1990, emissions per person have dropped by 27 per cent, and emissions per dollar of real GDP have fallen by half (52 per cent) (Figure ATM8). Australia's emissions intensity has been decreasing more strongly in recent years:

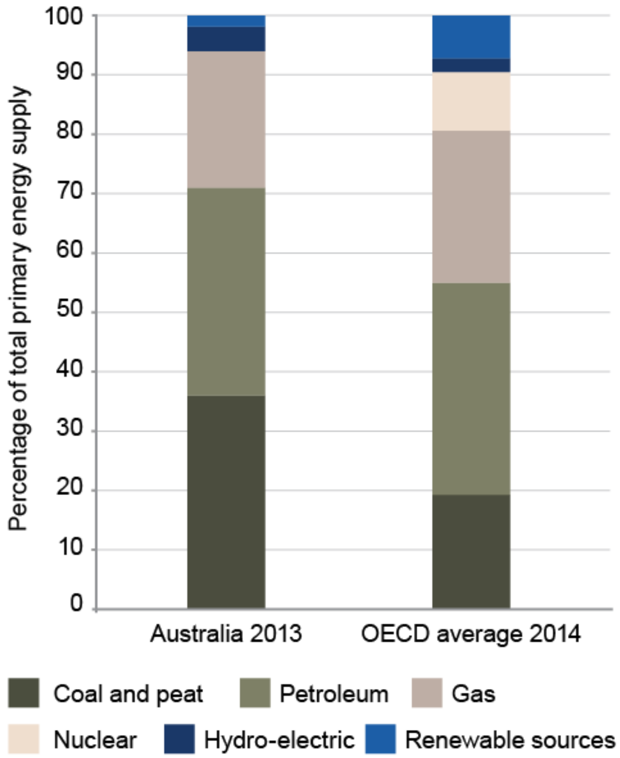
- In the past 10 years, emissions per person have decreased on average by 2.6 per cent per year, compared with an average decrease of 0.3 per cent per year between 1990 and 2005.
- In the past 10 years, emissions per dollar of real GDP have decreased on average by 3.7 per cent per year, compared with an average decrease of 2.4 per cent per year between 1990 and 2005.

Much of this decrease can be attributed to a decrease in the proportion of electricity generated from coal, as discussed in more detail under Analysis of emissions trend drivers.

Kyoto Protocol targets

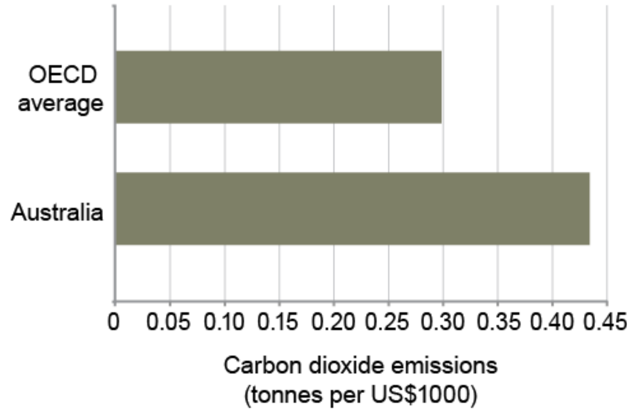
As a signatory to the Kyoto Protocol, ratified in 2007, Australia committed to limiting increases in net GHG emissions to 108 per cent of its 1990 levels from 2008 to 2012. The *National inventory report 2012* (DoE 2014a) demonstrates that Australia surpassed the Kyoto target, with emissions averaging 565 $MtCO_2$-e per year (2008–12), or 103 per cent of the 1990 base level (Figure ATM9).

Australia has now committed to reducing its GHG emissions to 99.5 per cent of 1990 levels for the Kyoto Protocol's second commitment period (2013–20). This is consistent with Australia's 2020 target to reduce emissions by 5 per cent below 2000 levels by 2020. In December 2015, the Prime Minister announced that Australia will ratify the second commitment period.



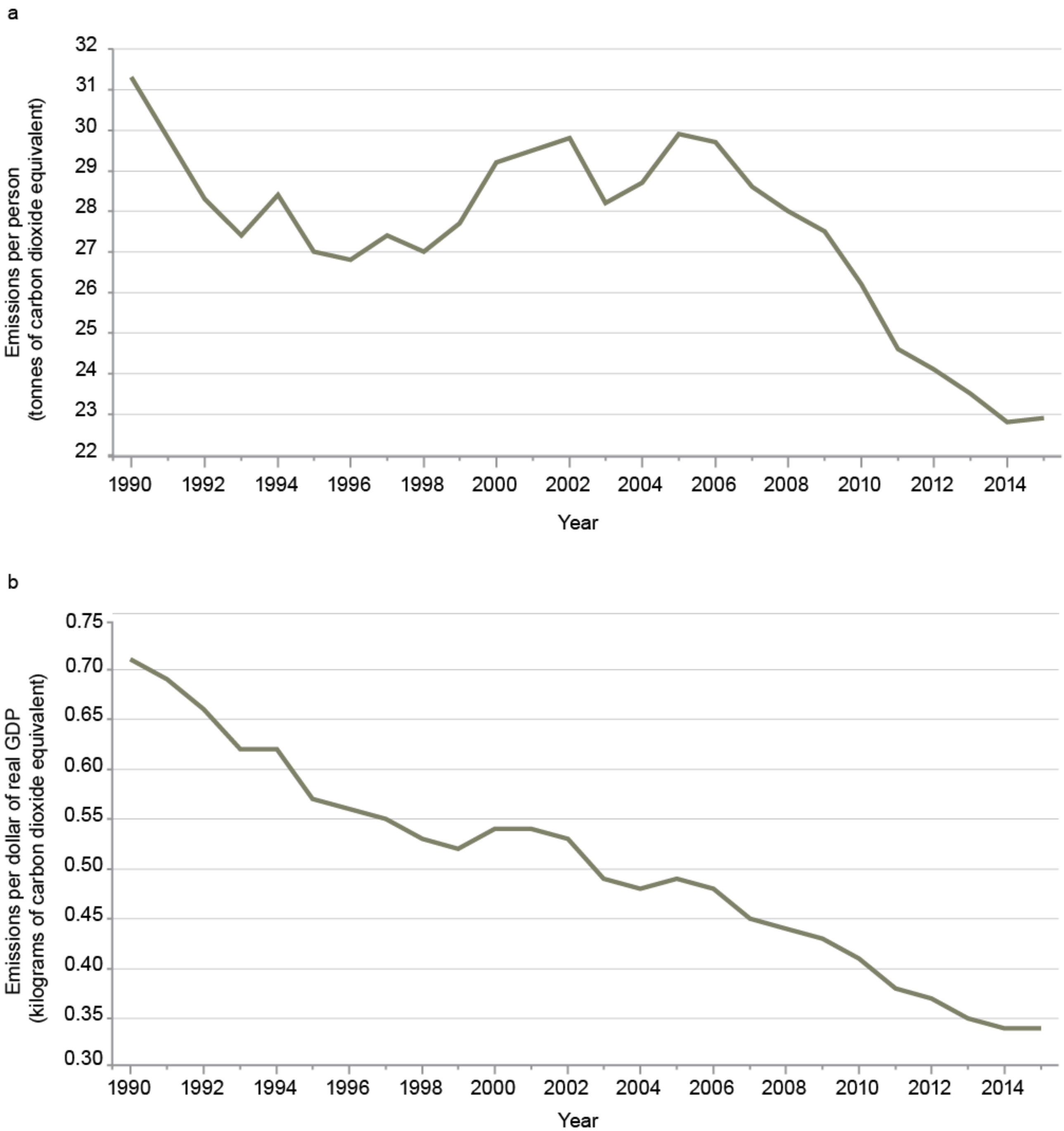
Source: IEA (2014, 2015)

Figure ATM6 Fuel mix contributing to total primary energy supply, Australia (2013) and OECD average (2014)



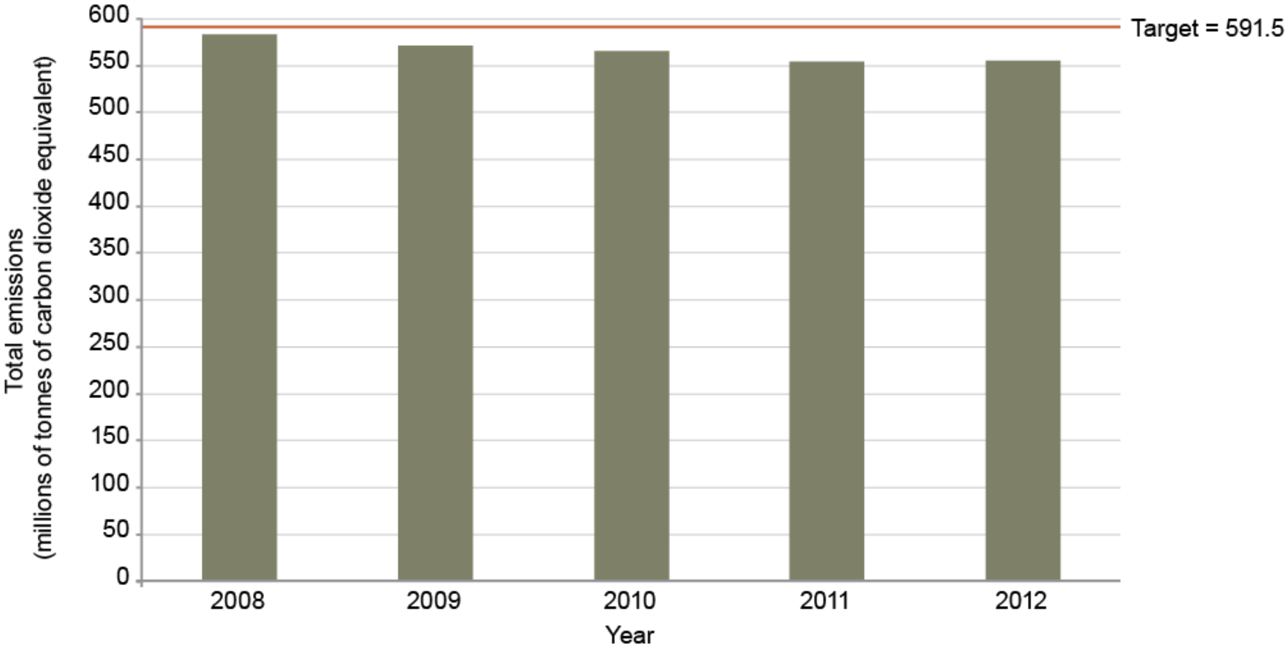
Source: OECD (2015)

Figure ATM7 Carbon dioxide emissions per US$1000, 2013



GDP = gross domestic product
Source: Australian Government (2015a)

Figure ATM8 Australia's annual emissions (a) per person, and (b) per dollar of real gross domestic product, 1990–2015



Source: DoE (2014a)

Figure ATM9 Australia's tracking against the Kyoto Protocol target, 2008–12

Trends in emissions

Absolute aggregate emissions

Between 1990 and 2015, Australia's national GHG inventory suggested that emissions decreased 0.1 per cent (Figure ATM10).

Since 2006, Australia's emissions (including land use, land-use change and forestry—LULUCF) have decreased by an average of 1.1 per cent per year. This compares with an average increase of 0.3 per cent per year from 1990 to 2000.

When LULUCF emissions are excluded from the determination of total emissions, emissions have generally increased. For example, between 2002 and 2007, the average growth rate was 0.9 per cent per year. During the global financial crisis, Australia, like most countries, experienced a lower growth in annual emissions, with emissions increasing by only 0.5 per cent between 2008 and 2009. By comparison, the United States and European Union reduced emissions growth by approximately 1.4 per cent per year during the same period.

Sectoral emissions

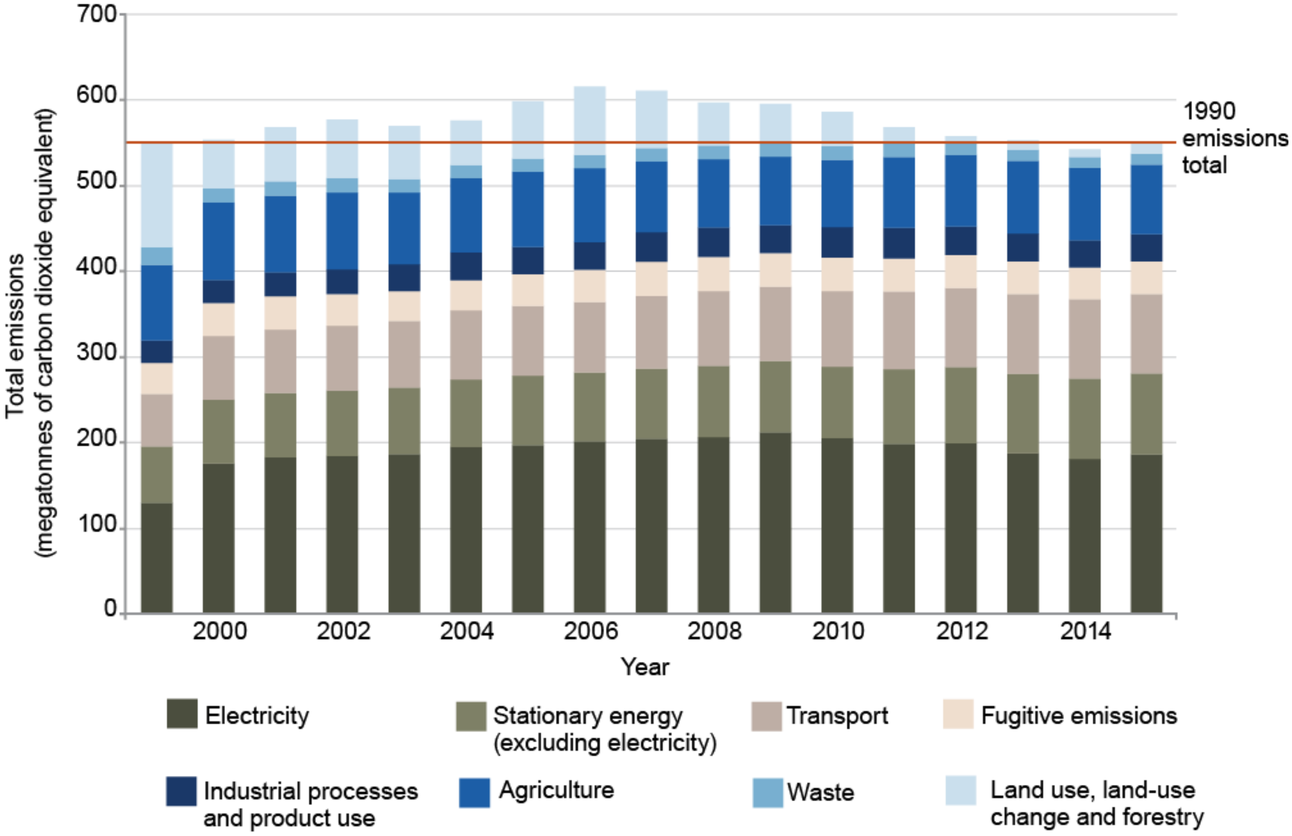
The energy sector generates emissions from stationary energy, transport, and fugitive emissions from fuel extraction. The sector continues to be the dominant source of Australia's GHG emissions, accounting for 76 per cent of net emissions in 2015 (Figure ATM11). Emissions from stationary energy have increased by 44 per cent, or 85 $MtCO_2$-e, since 1990. This increase has been driven by a mix of factors, notably rising population and household incomes, and growth in demand for energy associated with substantial increases in the export of resources.

Solid fuel emissions from stationary energy tend to fluctuate from year to year, depending on the volume of coal mined and the share of production from underground compared with surface mines. Increases in emissions in this subsector have not grown as fast, because the trend is for more activity from less emissions-intensive surface mines than for the more emissions-intensive underground mines.

Since 1990, emissions from crude oil and natural gas activities have decreased; however, this is in contrast to increasing production activity (particularly natural gas). This inverse relationship is largely attributed to technological improvements, particularly in Australia's natural gas distribution network.

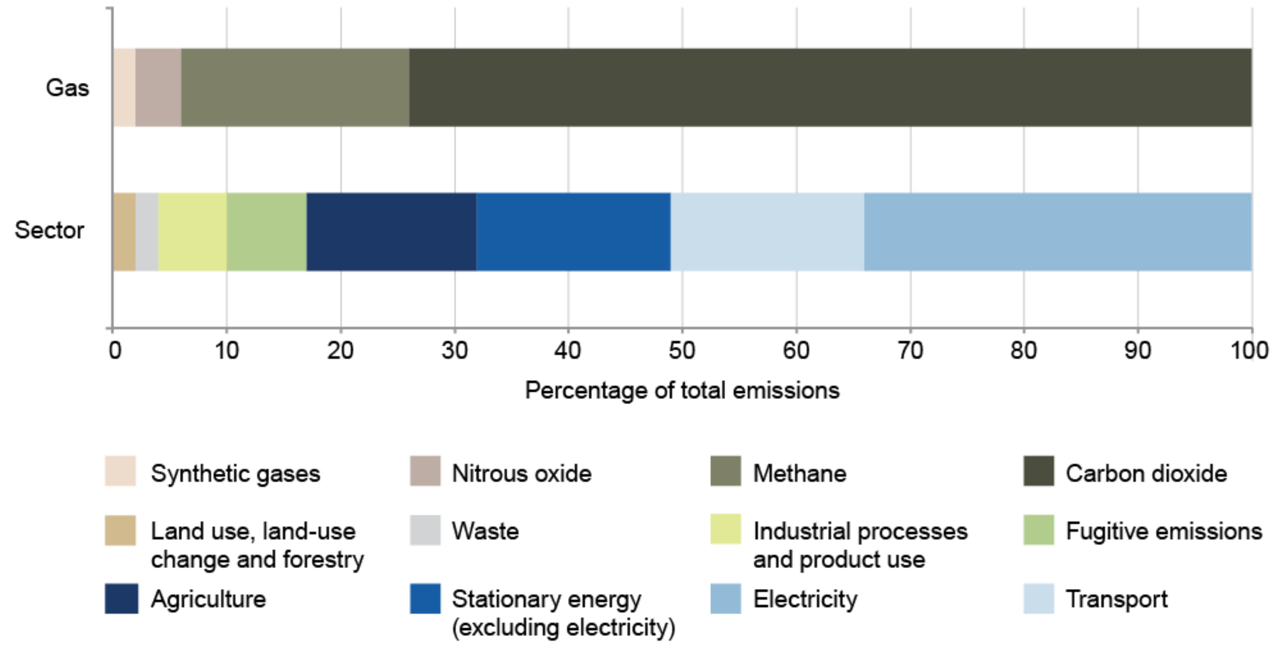
Fugitive emissions from fuel extraction occur during the production, processing, transport, storage, transmission and distribution of fossil fuels such as coal, crude oil and natural gas. This sector accounted for 7 per cent of Australia's GHG inventory in 2015. Emissions from this sector have increased by 5 per cent on 1990 levels, driven by an increase in emissions from solid fuel extraction (e.g. coal) of 13 per cent. This was partially offset by a decrease of 13 per cent in emissions from crude oil and natural gas extraction. Despite long-term declines, emissions from this subsector increased by 5 per cent between 2014 and 2015.

The transport sector generates emissions from the direct combustion of fuels in transportation by road, rail, domestic aviation and domestic shipping. The main fuels used for transport are automotive gasoline (i.e. petrol), diesel oil, liquefied petroleum gas and aviation turbine fuel. In 2015, transport accounted for 17 per cent of Australia's national GHG inventory. Emissions from transport have increased by 51 per cent, or 31 $MtCO_2$-e, since 1990. Transport emissions growth in Australia is relatively steady at around 2 per cent per year, in line



Source: Australian Government (2015a)

Figure ATM10 Australia's net greenhouse gas emissions by sector, United Nations Framework Convention on Climate Change accounting, 1990 and 2000–15



Source: Australian Government (2015a)

Figure ATM11 Greenhouse gas emissions by gas and sector, United Nations Framework Convention on Climate Change accounting, 2015

with population growth and an increase in the total kilometres travelled by main transport modes such as cars. This growth, however, has been partially offset by steady improvements in the fuel efficiency of cars and trucks.

Emissions from agriculture include methane and nitrous oxide from enteric fermentation in livestock, manure management, rice cultivation, agricultural soils, savanna burning and field burning of agricultural residues. Emissions from agriculture accounted for 15 per cent of Australia's GHG inventory in 2015. This sector is the dominant source of both methane and nitrous oxide emissions; it also includes CO_2 emissions from the application of urea and lime. Non-CO_2 emissions are reported under agriculture; however, CO_2 emissions and removals from savanna burning are reported under the LULUCF sector. Since 1990, agriculture emissions have fallen by 8 per cent, or 7 $MtCO_2$-e. Initially, this decline was driven by a fall in sheep numbers; however, by the late 1990s, it was balanced by increasing beef cattle numbers (reflecting changing relative returns to each industry). From 2002 to 2010, and then again in 2015, livestock populations declined in response to drought conditions. This, along with reduced production of many key crops in 2015, has also contributed to the reduction in agriculture emissions.

Industrial processes and product use (IPPU) includes emissions from processes used to produce chemical, metal and mineral products, as well as emissions from the consumption of synthetic gases. In 2015, IPPU accounted for 6 per cent of Australia's national GHG inventory. Since 1990, emissions from this sector have increased by 22 per cent, principally because of emissions growth from the manufacture of chemical products. In recent years, growth in this sector has been partially offset by the closure of Australia's only soda ash production facility in 2013, and declines in metal production associated with the permanent closure of a Port Kembla blast furnace in New South Wales in 2011 and the Point Henry aluminium smelter in Victoria in 2014.

The waste sector generates emissions from landfills, wastewater treatment, waste incineration and the biological treatment of solid waste. Emissions largely consist of methane, which is generated when organic

Sunset over Lake Burley Griffin and the carillon, Canberra
Photo by Megan Watson

matter decays under anaerobic conditions. In 2015, waste accounted for 2 per cent of Australia's national GHG inventory. Because waste degradation is a slow process, estimates of methane generation for 2015 reflect waste disposal for more than 50 years. Waste emissions have fallen by 38 per cent since 1990, mainly because of increases in methane recovery during the past 5 years, resulting from a combination of regulatory pressure and commercial gain through use of the methane as an energy source. It is also notable that, recently, as rates of recycling have increased, paper disposal in particular has declined as a share of total waste disposed. Total waste disposal has also declined in recent years as alternative waste treatment options become more viable, driven by state and territory waste management policies.

The LULUCF sector includes estimates of net anthropogenic emissions for forests and agricultural lands, and changes in land use. The principal subclassifications of the LULUCF sector under the Kyoto Protocol classification system are deforestation, forest management, afforestation and reforestation, grazing land management, and crop land management. The sector accounted for 2 per cent of Australia's GHG inventory in 2015. Net emissions from LULUCF have decreased by 88 per cent since 1990, predominantly driven by a decline in emissions from deforestation and grazing land management.

Emission levels of the LULUCF sector tend to vary significantly from year to year, reflecting climate variability. Peaks are often associated with extreme events such as bushfires and drought, which lead to major loss of carbon from vegetative and soil sinks. This results in large variations in the GHG emissions profile of the sector from year to year; in some years, this sector is a net source of emissions, whereas, in other years, it is a net sink.

Sectoral emissions profiles

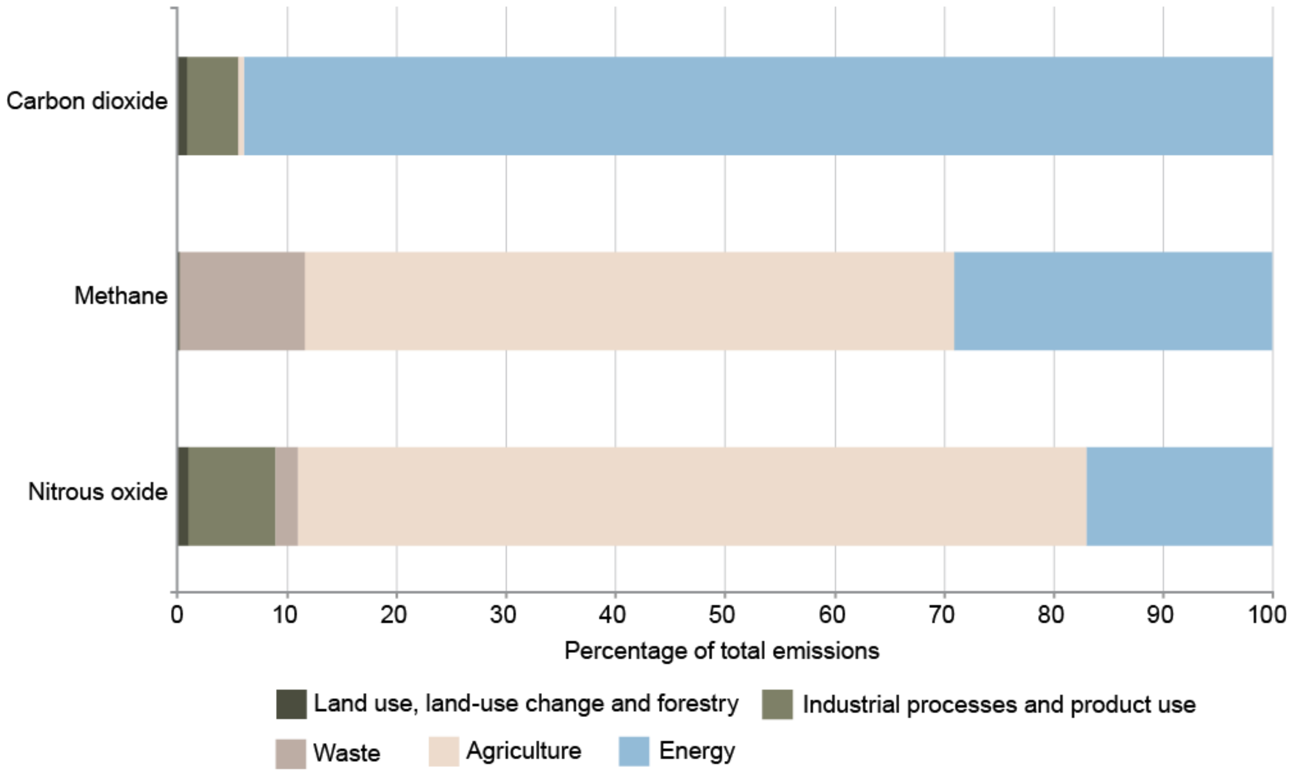
Each of the sectors in Australia's inventory has a different emissions profile (Figure ATM12).

Most of the CO_2 emissions in the 2015 inventory occurred in the energy sector, contributing 93.9 per cent.

Most methane and nitrous oxide emissions in the 2015 inventory occurred in the agriculture sector, contributing 59.3 per cent and 72.0 per cent, respectively (see also Box ATM9).

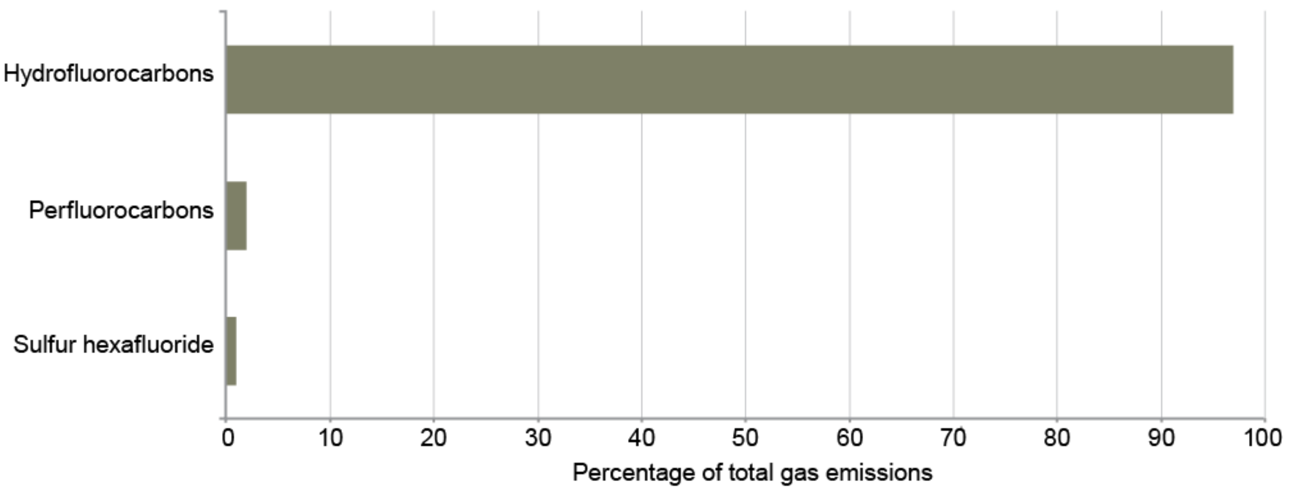
Although 96 per cent of waste emissions consist of methane, this sector represents only 11.4 per cent of methane emissions in the inventory.

Emissions from IPPU are also CO_2 rich, despite contributing only 4.7 per cent of total CO_2 emissions. This sector is unique in that all synthetic gas emissions in the inventory, which include HFCs, PFCs and SF_6, are sourced from IPPU (Figure ATM13).



Source: Australian Government (2015a); Australian Government Department of the Environment and Energy, unpublished emissions estimates, 2016

Figure ATM12 Carbon dioxide, methane and nitrous oxide emissions by sector, United Nations Framework Convention on Climate Change accounting, 2015



Source: Australian Government (2015a); Australian Government Department of the Environment and Energy, unpublished emissions estimates, 2016

Figure ATM13 Synthetic gas emissions by gas type, 2015

Analysis of emissions trend drivers

An equation known as the Kaya identity (equation 1), developed by the Japanese energy economist Yoichi Kaya in 1993 and used by the IPCC in the development of future emissions scenarios, supports the previous analysis of the drivers of Australia's emissions trends. The equation expresses CO_2 emissions from fuel combustion and IPPU as the product of 4 factors: population, GDP per person, the energy intensity of the economy, and the emissions intensity of the energy.

Equation 1: CO_2 from fuel combustion and IPPU

$$= P \times \frac{GDP}{P} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

where:

P = population

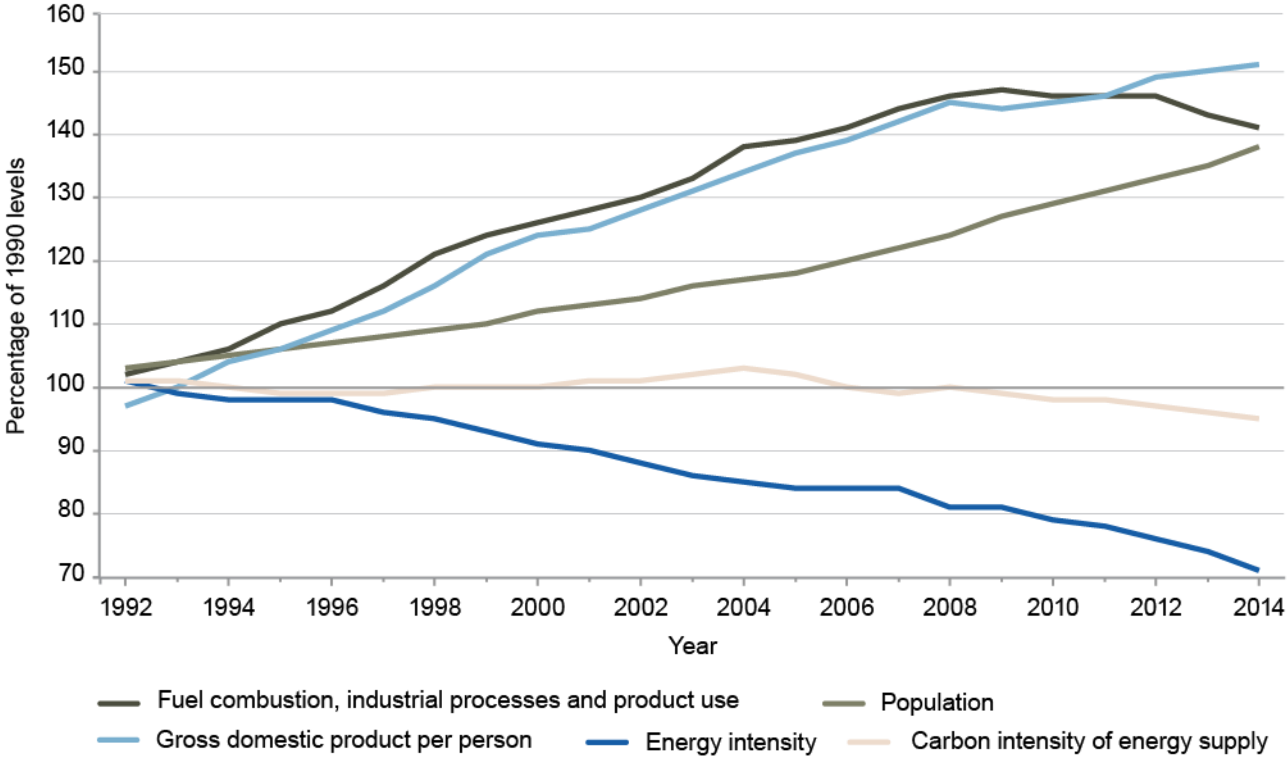
GDP = gross domestic product

Energy = total net energy consumption

CO_2 = CO_2 emissions from fuel combustion and IPPU

Trends in these factors provide an insight into how Australia's national circumstances have affected CO_2 emissions since 1990. However, it should be noted that each factor is not necessarily independent of each other (e.g. increases in GDP per person may change the energy intensity of the economy), and an increase in a single factor will not automatically result in a corresponding change in CO_2 emissions (e.g. an increase in population does not automatically result in an equivalent increase in CO_2 emissions).

Between 1990 and 2014, CO_2 emissions from fuel combustion and IPPU increased by 41 per cent (Figure ATM14). Underlying growth factors were a 38 per cent increase in population and a 51 per cent increase in GDP per person. Factors contributing to a decline were a 29 per cent decrease in the energy intensity of the economy and a 5 per cent decrease in the emissions intensity of energy consumption. During the period, Australia's CO_2 emissions trended upwards until 2009, before declining to 2014 as the impact of improved energy intensity of the economy



Source: Australian Government (2015a)

Figure ATM14 Carbon dioxide emissions from fuel combustion, industrial processes and product use, and underlying drivers, 1992–2014 and lower emissions intensity of energy more than offset increases in population and GDP per person.

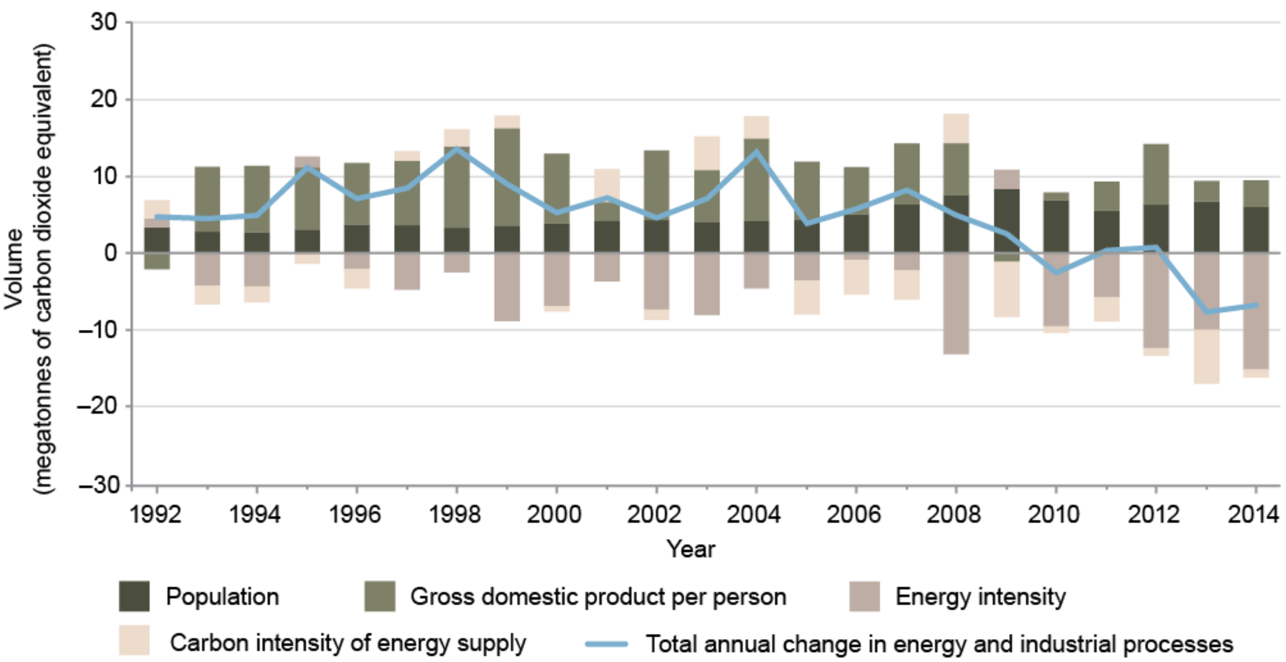
Figure ATM15 attributes annual emissions changes to the 4 underlying factors. The combined impact of increases in population and GDP per person have contributed to increasing emissions in all years. The energy intensity of the economy decreased in 20 of the 23 years at varying rates per year, reflecting energy efficiency improvements and structural change in the economy towards less energy-intensive service sectors. The emissions intensity of energy has fluctuated during the timeseries; a declining trend has been seen since 2005 as the proportion of electricity generation from coal has declined.

This analysis considers a subset of Australia's total emissions. At the national level, increases in CO_2 emissions from fuel combustion and IPPU have been offset by declines in other emissions sources. Figure ATM16 expands the decomposition to include other emissions sources as a fifth driver of total emissions. This analysis does not attempt to break down other emissions into underlying drivers such as energy consumption, population or GDP growth, which have less of an effect on these types of emissions.

Changes in other emissions sources generally have a downwards impact on total emissions, but annual changes are subject to considerable variation.

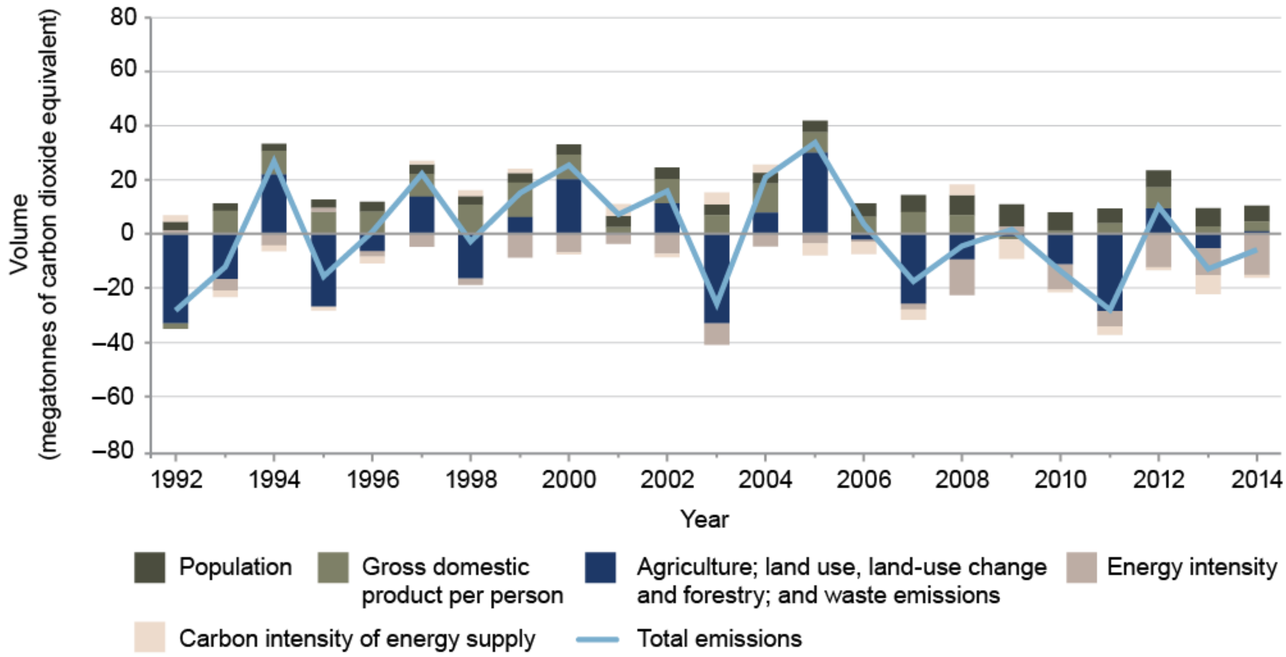
Direct (primary) effects of pressures on climate

The CSIRO and Bureau of Meteorology *State of the climate 2014* (CSIRO & BoM 2014) concluded that, in the coming decades, Australia's temperatures are projected to continue to rise. This rise will manifest as an increase in the number of hot days and warm nights, and a reduction in the number of cool days and cold nights. By 2030, projections show average temperatures rising by 0.6–1.5 °C (compared with the climate of 1980–99), in addition to an existing rise of around 0.6 °C between 1910 and 1990. By 2070, if growth in GHG emissions continues in line with past trends, projected warming



Source: Australian Government (2015a)

Figure ATM15 Annual change in carbon dioxide emissions from fuel combustion, industrial processes and product use, and underlying drivers, 1992–2014



Source: Australian Government (2015a)

Figure ATM16 Annual change in total emissions from underlying drivers, 1992–2014

will be in the range of 2.2–5.0 °C. For low GHG emissions scenarios (which assume a significant reduction in global emissions in the coming decades), the projected increase is 1.0–2.5 °C.

Changes in average rainfall across Australia will also occur. By 2070, average rainfall across southern Australia is projected to decrease compared with the climate of 1980–99: between 0 and 20 per cent decrease under low GHG emissions scenarios, and between 30 per cent decrease and 5 per cent increase under high emissions scenarios. The largest decreases will occur in winter and spring. For northern Australia, the projected changes in rainfall range from a 20 per cent decrease to a 10 per cent increase by 2070 for low emissions scenarios, and a 30 per cent decrease to a 20 per cent increase for high emissions scenarios (CSIRO & BoM 2014).

Anthropogenic climate change may also alter the frequency and severity of extreme events, such as storms (tropical cyclones, storm surges, severe winds and hail), floods, droughts, heatwaves and fires. The IPCC has summarised the projections of climate change and some extreme events for Australia (see Reisinger et al. 2014; Figure ATM17):

- Tropical cyclones are projected (with low confidence) to decrease in occurrence, but their intensity is projected to increase. One modelling study showed (with low confidence) a 50 per cent reduction in tropical cyclone occurrence for 2051–90 relative to 1971–2000, increases in intensity of the modelled storms, and occurrence around 100 kilometres further south (Abbs 2012). Limited studies have shown a projected decrease in the frequency of cool-season tornadoes (Timbal et al. 2010), and increases in the frequency and intensity of hail in the Sydney region (Leslie et al. 2008).
- Extreme precipitation events are projected (with medium confidence) to increase in intensity. Flood risk in the north of Australia (driven by convective rainfall systems) will be greater than in the south of Australia, where more intense extreme rainfall will be offset by drier precursor moisture conditions (Alexander & Arblaster 2009, Rafter & Abbs 2009).

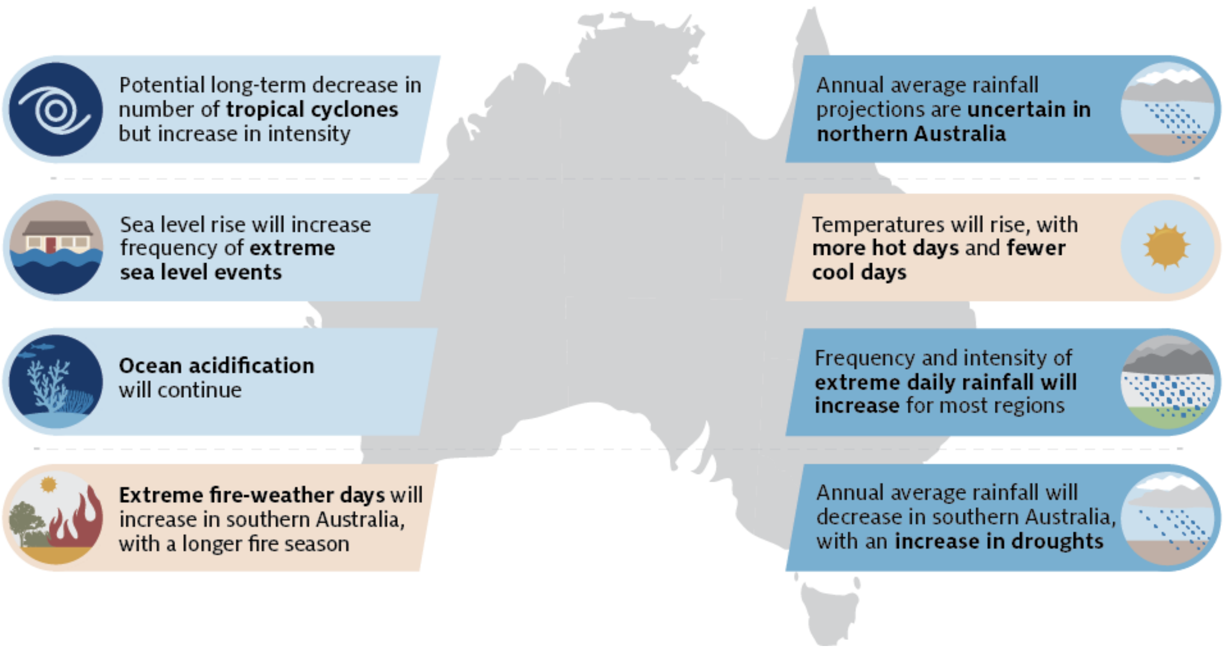


Figure ATM17 Summary of climate change projection scenarios for Australia

- Sea level rise is projected (with a high level of confidence), which will result in an increase in the frequency of extreme sea level events. Changes in storm surges will play a lesser role (McInnes et al. 2013).
- Droughts are projected (with a medium level of confidence) to become more frequent and severe in southern Australia, with projected changes being more pronounced during winter and spring (Irving et al. 2012).
- Heatwaves are likely to become more frequent, with hot days and nights projected with high confidence to become more frequent (CSIRO & BoM 2014).
- The number of days with very high and extreme fire weather is expected to increase, more so in southern Australia, where fire is weather constrained, than in the tropical savannas of northern Australia, where fire is constrained by fuel load and ignitions. The length of the fire season will also increase in many already high-risk areas, thus reducing opportunities for controlled burning (Lucas et al. 2007). In addition, higher CO_2 levels may increase vegetation growth, thus increasing fuel loads in some regions (Bradstock 2010, Hovenden & Williams 2010, King et al. 2011).

A number of these changes may be attributable to a mixture of climate change and natural processes. In any case, improving our understanding of the vulnerabilities associated with such changes is an essential step in planning our adaptation to climate change.

Indirect (secondary and tertiary) effects of pressures on climate

Changes in temperature and precipitation, and extreme events trigger indirect effects of climate change on the environment, affecting economic and social processes and systems, and natural ecosystems. Australia's sixth national communication on climate change to the United Nations Framework Convention on Climate Change summarises the wide range of indirect effects of climate change for Australia (DIICCSRTE 2013):

- Water—decreased rainfall in southern Australia and south-western Western Australia, increased evaporation, and reduced run-off to streams and recharge to groundwater systems will result in decreased water availability and decreased water security (see the *Inland water* report).

- Coasts—sea level rise will result in greater coastal inundation, loss of wetlands, salt water mixing into freshwater sources, and erosion affecting coastal infrastructure and resources. Changes to weather patterns, ocean currents, ocean temperature, storm surges and ocean acidification could also affect coasts (see the *Coasts* report).
- Infrastructure—climate change will result in damage to energy, water, communications and built infrastructure. The interdependencies between critical infrastructure sectors complicate the likely effects of climate change on infrastructure. For example, extreme event damage to the electricity network would affect telecommunications and transportation infrastructure (see the *Built environment* report).
- Agriculture—climate change will result in a decrease in agricultural activity. Drought disrupts cropping, reduces stock numbers and erodes the resource base of farms. Severe storms, hailstorms, cyclones and floods destroy crops, damage infrastructure and interfere with activities such as harvesting and planting. Managing climate variability will become increasingly difficult for Australian primary producers, given the projected changes in mean temperature and precipitation that will be superimposed on large climate variability.
- Iconic natural systems—climate change is likely to intensify the effects of existing threats and enhance the cumulative impacts on iconic natural systems. For example, for Kakadu National Park, likely climate change impacts include rising sea levels, saltwater intrusion, changing fire patterns, and invasive flora and fauna. In the near term, increasing sea temperatures will damage coral systems on the Great Barrier Reef, and, in the long term, ocean acidification will damage oceanic calcifying organisms on the Reef.
- Human health—climate change will have some direct impacts on human health, such as the effects of heatwaves. Other effects could occur indirectly through disturbances of natural ecological systems, such as changes in the range and activity of mosquito populations (Bambrick et al. 2008, Åström et al. 2012), or increased fire activity that could result in the degradation of air quality in rural and urban centres (Keywood et al. 2013). The psychological impacts of climate change are likely to grow. Studies based on impacts of recent climate variability and extremes are being documented (Doherty & Clayton 2011); they indicate significant mental health risks associated with climate-related disasters—in particular, persistent and severe drought, floods and storms. These impacts are most acute in rural communities where climate change places additional stresses on livelihoods (Edwards et al. 2009).

Sunset over Lake Burley Griffin and the High Court, Canberra
Photo by Megan Watson

Assessment summary 1

Pressures affecting Australia’s climate

Component	Summary	Assessment grade: Very high impact	High impact	Low impact	Very low impact	Confidence: In grade	In trend	Comparability: To 2011 assessment
Greenhouse gases	Greenhouse gas (GHG) emissions have increased since the industrial age, causing positive radiative forcing and increasing global temperatures Australia’s emissions per capita are high relative to other nations in the Organisation for Economic Co-operation and Development; however, emissions decreased between 1990 and 2015 GHG emissions will continue to place pressure on the climate, with changes in temperature, rainfall and extreme events		↙			●	●	◆

Recent trends

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

Grades

- **Very low impact:** Few or no impacts have been observed, and accepted predictions indicate that future effects are likely to be minor
- **Low impact:** Current pressures have been observed to have had a limited impact on some aspects of climate, and there is concern that, based on accepted predictions, these may worsen
- **High impact:** Current pressures are probably already having serious impacts on important aspects of climate and are expected to worsen, with serious implications for a broad range of areas
- **Very high impact:** Current pressures are already having very serious impacts on important aspects of climate (such as temperature, rainfall and extreme events), with very serious flow-on effects in a broad range of areas

Confidence

- ● **Adequate:** Adequate high-quality evidence **and** high level of consensus
- ◕ **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- ◒ **Limited:** Limited evidence **or** limited consensus
- ◔ **Very limited:** Limited evidence **and** limited consensus
- ○ **Low:** Evidence and consensus too low to make an assessment

Comparability

- ◆ **Comparable:** Grade and trend are comparable to the previous assessment
- ⬙ **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- ◇ **Not comparable:** Grade and trend are not comparable to the previous assessment
- **X** **Not previously assessed**

State and trends
of Australia's climate

At a glance

Australian temperatures have increased during the past 100 years, especially since the 1950s. This increase has also been observed at the global level, and is associated with increasing concentrations of greenhouse gases in the atmosphere. The year 2015 was the warmest on record for the globe. The shift towards higher temperatures has been associated with regional increases in the frequency, duration and intensity of extreme heatwaves. The past few years have seen a number of these extreme heat events across Australia, with the record hot summer of 2012–13 having the warmest month, week and day on record. The year 2013 was Australia's warmest year on record. Spring 2014 was Australia's warmest spring on record, followed by spring 2015 and spring 2013.

Australian rainfall has been highly variable during the past 100 years, particularly in the past 40 years. The millennium drought began in 2000, and ended in 2010 with Australia's wettest 2-year period on record, which was associated with strong La Niña events in the tropical Pacific (La Niña events tend to result in above average rainfall for much of Australia). After that, drought re-emerged across large areas of southern and eastern Australia, including Queensland. Long-term rainfall deficiencies across Victoria, Tasmania, south-eastern South Australia and south-western Western Australia are overlaid on a long-term trend of declining rainfall in autumn and winter (the southern wet season) in parts of south-eastern and south-western Australia. The strong El Niño event of 2015–16 further reinforced these dry conditions across large parts of eastern Australia.

Temperature

Australia's climate has warmed since national temperature records began in 1910, with mean surface air temperature showing around a 1 °C warming since then (Figure ATM18).

Concurrent with the warming trend in Australian land temperatures, temperatures in the oceans surrounding Australia have also continued to increase (Figure ATM19). The surrounding and neighbouring oceans play a highly influential role in the variability of Australia's climate. Large-scale drivers in the Indian and Pacific oceans, such as ENSO (with El Niño and La Niña phases), affect our climate on a range of timescales. Warm temperature anomalies and record warmth have persisted in the Indian Ocean in the past decade. On a smaller scale, regions in Australia can also be affected by changes in sea surface temperatures in Australia's immediate vicinity. Warming from the middle of the past century is most pronounced along the southern Australian coasts and the Tasman Sea, possibly associated with a southwards extension of the East Australian Current.

The warming trend in mean temperatures has been accompanied by a large increase in extreme temperatures. The shift in mean temperature has seen fewer cold records broken and more warm records broken. Since 2001, the number of extreme heat records in Australia from station data has outnumbered extreme cool records by almost 3 to 1 for daytime maximum temperatures, and almost 5 to 1 for night-time minimum temperatures (Trewin & Vermont 2010, Trewin & Smalley 2013).

Most notably, heatwaves have increased in frequency, duration and intensity in many parts of the country (Alexander et al. 2006, Alexander & Arblaster 2009, Perkins et al. 2012). Recent years have seen a number of significant heat records broken across the Australian continent. Heatwaves can have large impacts on human

Cumulus clouds formed from intense bushfires in the King Valley as seen from El Dorado, Victoria
Photo by John Baker

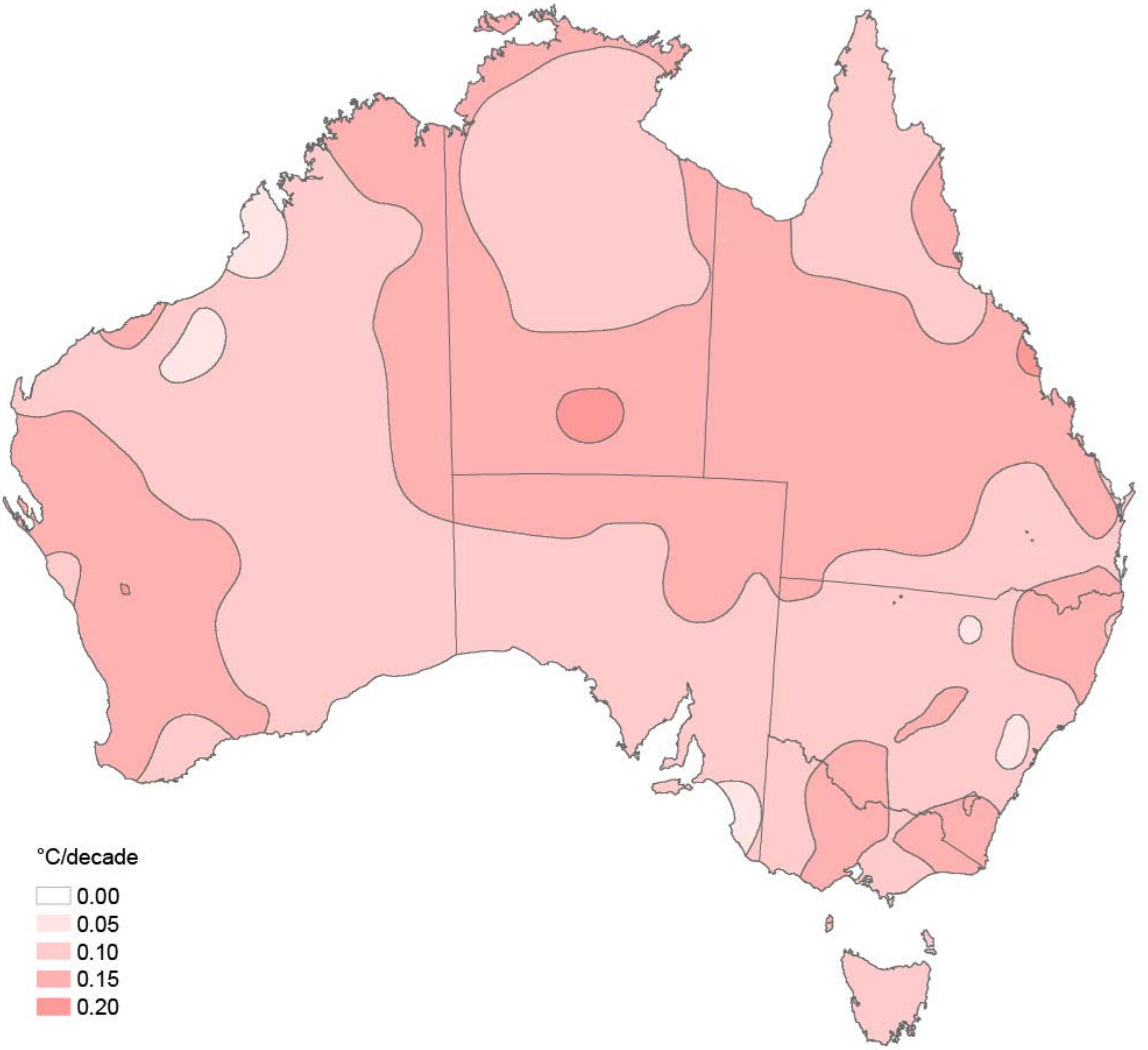
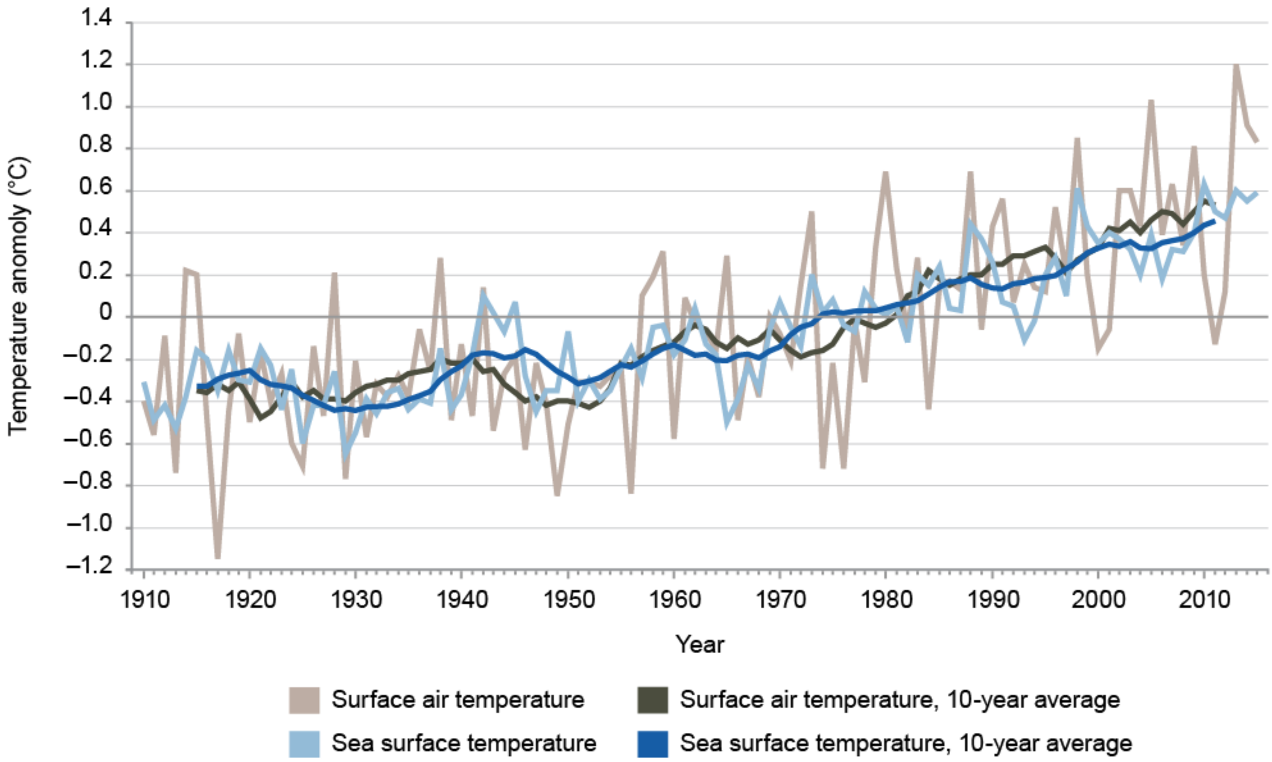


Figure ATM18 Trends in Australian mean temperatures, 1910–2015

health, the severity of fire weather, and other biological and ecological systems (Box ATM3). The nature of the heatwaves is changing in many parts of Australia—they are becoming more frequent, more intense, of longer duration and over a larger area. Since SoE 2011, several widespread extreme heat records have been broken.

The increase in mean temperatures since 1910 has also affected the frequency of warm months. Very warm monthly maximum temperatures were 5 times more likely to occur in 2001–15 than in 1951–80. The frequency of very cool monthly night-time temperatures declined by around one-third during the same period (CSIRO & BoM 2016).

Australia's warmest year on record was 2013, with summer 2012–13 the warmest on record and spring 2013 the warmest at the time. The spring record was broken the following year in 2014, and 2014 was the third warmest year on record. Spring in 2015 was the second warmest



Source: Bureau of Meteorology

Figure ATM19 Timeseries of anomalies in sea surface temperature and temperature across land in the Australian region, 1910–2015

on record. Summer 2012–13 was especially intense in terms of total heat, with Australia's area-averaged hottest month, hottest week and hottest day on record, and the longest and most spatially extensive national heatwave on record (BoM 2013).

The science can now partially attribute the likelihood, frequency, extent and severity of record heat events to increasing mean temperatures because of anthropogenic climate change. For example, the record-breaking temperatures experienced in Australia during 2013 are extremely unlikely to occur in a climate that does not include warming as a result of increased GHGs. Studies investigating fraction attributable risk from increasing GHGs have shown a 5-fold increase in the odds of extreme heat when comparing simulated climates with and without an enhanced greenhouse effect. For example, there is a 5-fold increase in the odds of experiencing the record hot Australian summer of 2012–13, when Australia experienced its hottest day, week and month on record (Lewis & Karoly 2013).

The extreme anomalous heat experienced during the (at the time) record-breaking spring of 2013 was even less likely to have occurred without anthropogenic forcing. The enhanced greenhouse effect made the 2013 hot spring more than 50 times more likely to occur (Lewis & Karoly 2014) when compared with a pre-industrial climate. A study using a detailed modelling and statistical approach found that global warming likely contributed up to 15 per cent of the record September 2013 temperature anomaly (Arblaster et al. 2014). Likewise, the subsequent record-breaking spring of 2014—specifically the anomalously warm months of October and November—was in large part caused by circulation changes because of the upwards trend in oceanic temperatures in response to increased CO_2 levels in the atmosphere across several years (Hope et al. 2015).

However, to fully describe recent variations in Australia's climate, it is necessary to consider the influence of both natural climate variability and anthropogenic global warming. The combined influence of natural and human drivers has had a significant impact on Australian weather and climate in recent decades. For example, instances of record-breaking temperatures that have occurred this century have typically resulted from periods of low rainfall combined with background warming. The La Niña year of 2011 was the first year with an annual mean temperature below average since 2001, mostly as a result of below average maximum temperatures associated with the widespread rainfall.

Rainfall

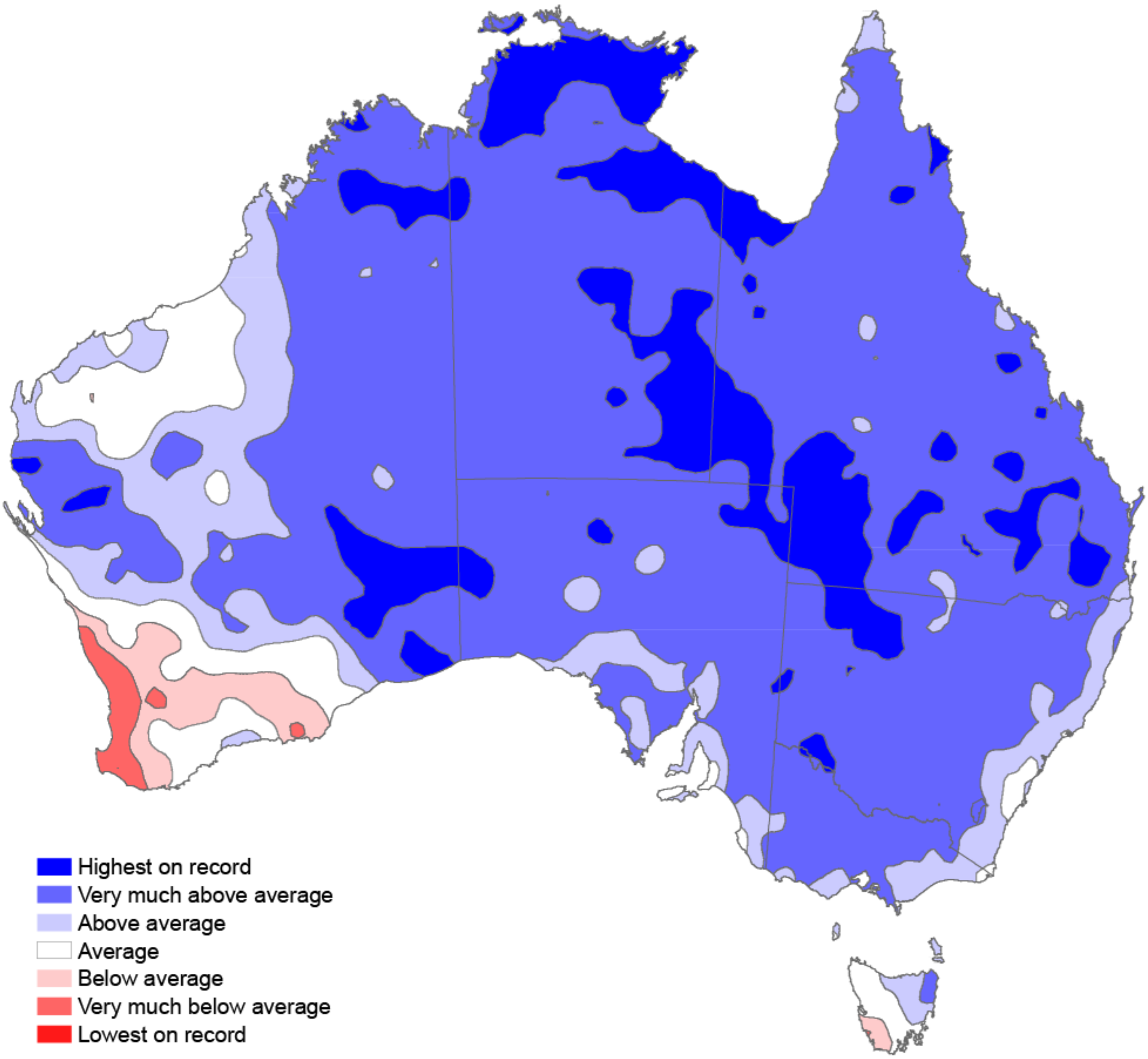
Broadly, Australia can be divided into 2 seasonal rainfall regimes: the north and the south. The northern half of the continent typically experiences a monsoonal, summer wet season, with rainfall falling from October through April, and the rest of the year being dry. The southern half of the continent—particularly southern parts of Western Australia and South Australia, and the whole of Victoria and Tasmania—experiences its highest rainfall during the cooler months from April through November.

Rainfall in Australia is highly variable, largely because of large-scale atmospheric and oceanic drivers that affect the region. The most important driver of Australian rainfall variability is ENSO, particularly for rainfall across eastern Australia, excluding Tasmania. This leads to very high year-to-year rainfall variability, such that long-term trends because of climate change are harder to distinguish than for temperature. For example, a trend towards higher rainfall in association with the northern monsoon since the 1970s is not statistically significant when compared with natural rainfall variability. However, a drying trend in south-western and south-eastern rainfall during the first half of the southern growing season is broadly consistent with expected patterns of change because of global warming (Whetton et al. 2015).

Rainfall in Australia has displayed both large natural variability and large trends during the past 2 decades. Large parts of Australia suffered an extended period of low rainfall during the millennium drought of 2000–10 (which in some areas began as early as 1997 and ended as late as 2012). This was followed by drought-breaking rain associated with Australia's wettest 2-year period on record in 2010 and 2011, which were the result of 2 strong La Niña events (Figure ATM20). This record rainfall fell during the summer or northern monsoon seasons, and was not associated with a recovery in southern wet-season rainfall.

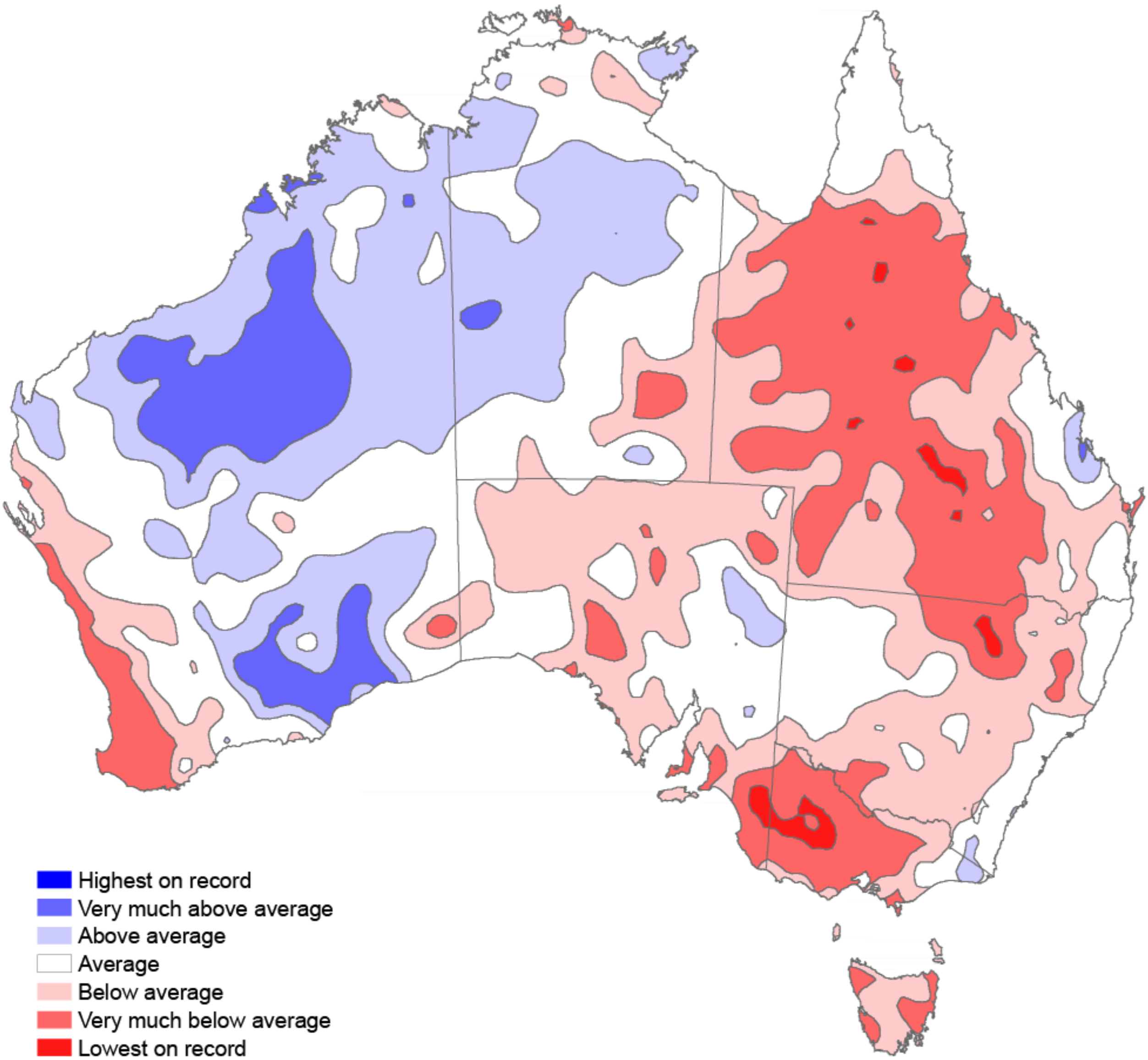
Since the 2011 La Niña, drought has re-emerged across large parts of Australia, especially western Queensland, northern New South Wales and western Victoria (Figure ATM21). The opposite ENSO phase to La Niña, El Niño, occurred in 2015 and is associated with below average rainfall across large areas of eastern Australia. This was especially challenging for the areas of south-western Western Australia, Queensland into northern New South Wales, and central to western Victoria, across the border into South Australia, that had seen the re-emergence of drought conditions after the 2 La Niña years. However, for some areas, near-record temperatures in the Indian Ocean are likely to have moderated the drying influence of the 2015 El Niño on Australia. The Indian Ocean has been at near-record temperatures for close to 10 years, with significant impacts on the climate of Australia.

Rainfall during the 2 La Niña years and the subsequent drought has taken place against a background of a long-term rainfall decline in parts of southern Australia, which has now persisted for decades (Figure ATM21). This rainfall decline has occurred during the first half of the southern growing season, which is an important time both for agriculture and for initial wetting of catchment areas to lay the foundations for the winter catchment and dam recharge period. The south-west of Western Australia has experienced a 10–20 per cent drop in winter rainfall since around 1970, which has been expressed as a step-change or series of step-changes, rather than a gradual decline. This period also lacked the high rainfall years that were common before that period. The south-east of the continent has experienced a similar decline in late autumn and early winter rainfall since around the mid-1990s. These rainfall changes have been accompanied by much larger reductions in streamflow, particularly in the south-west.



Source: Bureau of Meteorology

Figure ATM20 Rainfall deciles in Australia, 1 January 2010 – 31 December 2011



Source: Bureau of Meteorology

Figure ATM21 Rainfall deciles in Australia, 1 July 2012 – 31 October 2015

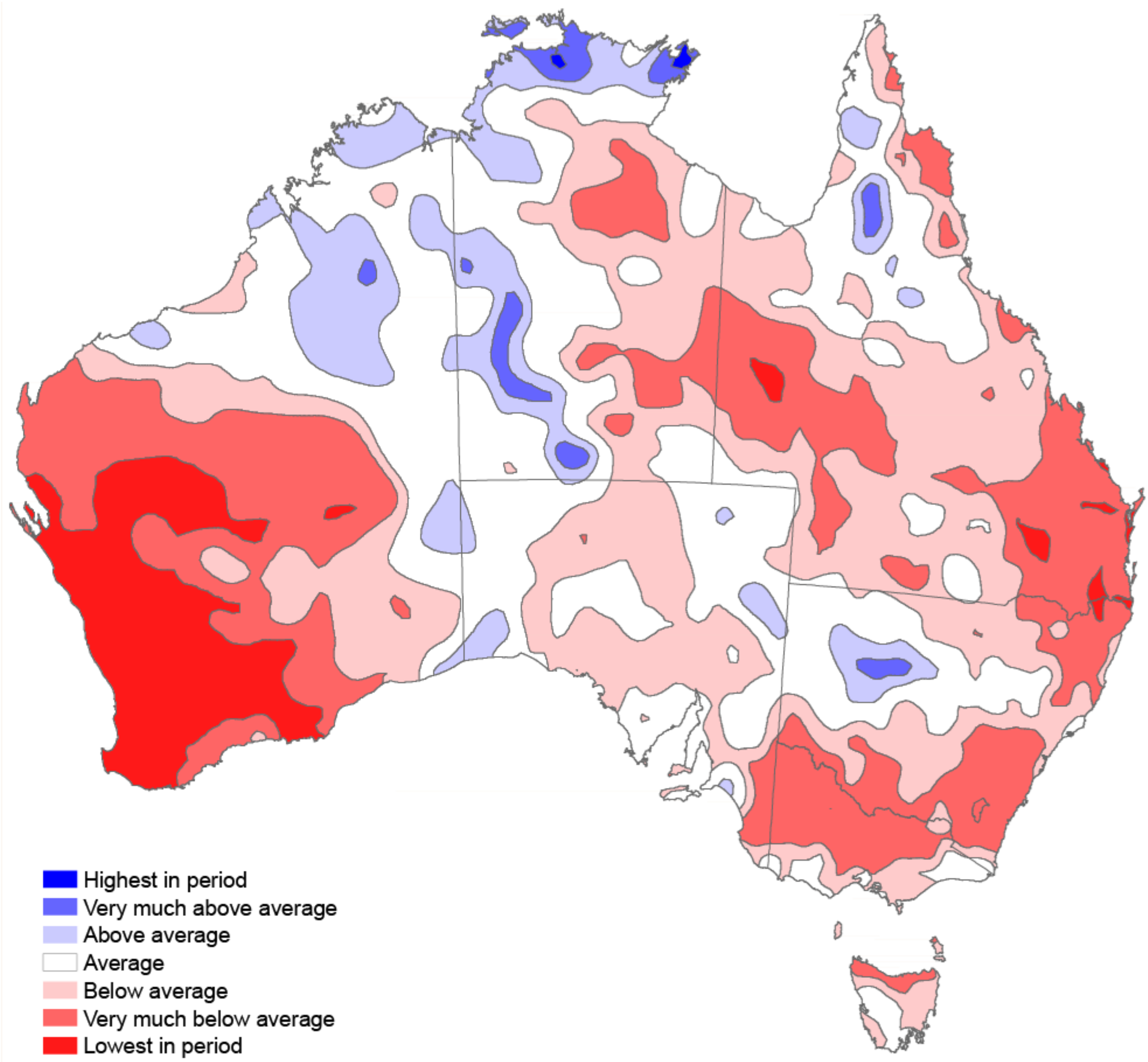


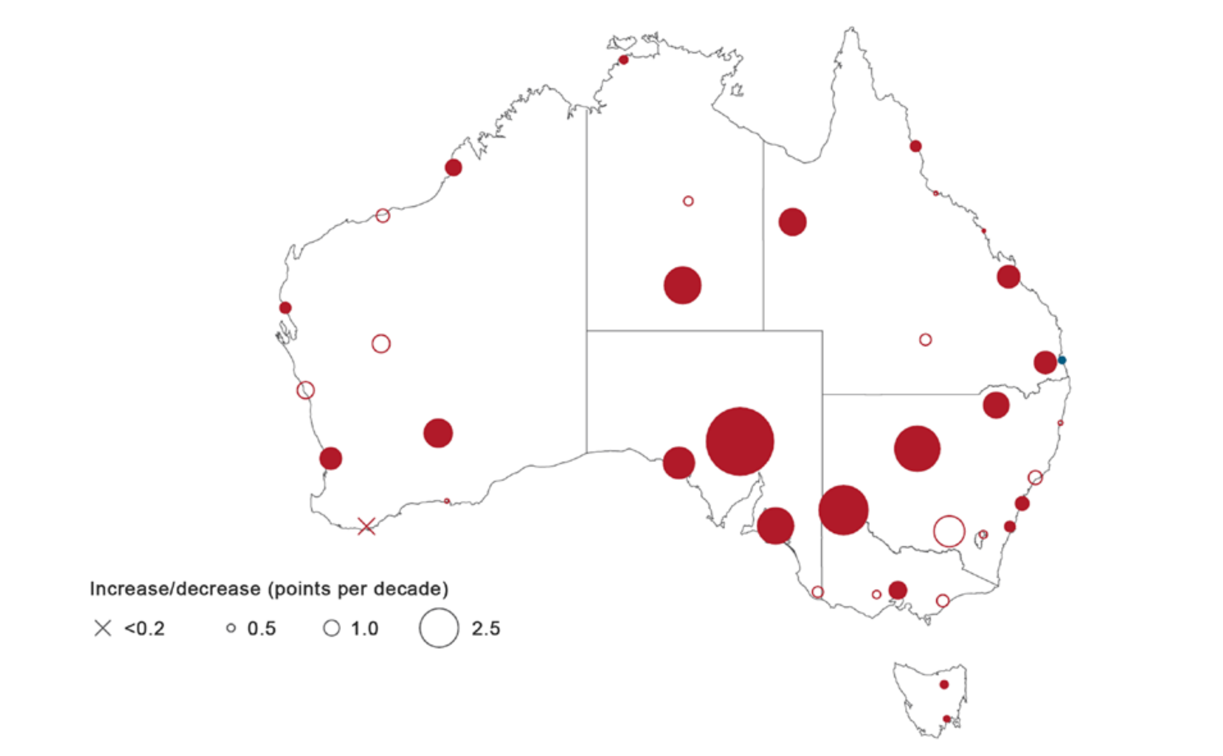
Figure ATM22 Noncontiguous rainfall deciles in Australia, May–July 2000–15

Box ATM3 Fire weather

Australia is one of the most fire-prone regions in the world. The fire season is distinctly different across the continent, occurring during the dry season in northern Australia, spring and summer in the subtropics, and middle to late summer in southern regions. The potential for fire at any given location or time is dependent on the availability and dryness of fuel (dry vegetation is more conducive to fire), and suitable weather conditions (hot, dry and windy conditions generally support fire growth) (Bradstock 2010).

Fire activity is sensitive to many different factors. Meteorological factors include wind speed, humidity, temperature and drought. Fire weather is monitored in Australia using the Forest Fire Danger Index (FFDI), which is calculated from daily temperature, wind speed, humidity and a drought factor at sites with consistent data across Australia (Lucas 2010). An increase in the annual (July–June) cumulative FFDI was observed across all 38 climate reference sites analysed in Australia from 1973 to 2010, and is statistically significant at 16 of those sites (Clarke et al. 2013), particularly in the south-east of the country. This increase across south-eastern Australia is characterised by an extension of the fire season further into spring and autumn (Clarke et al. 2013). Extreme fire-weather days have become more prevalent at 24 of the 38 locations since the 1970s.

Figure ATM23a maps the trends in extreme fire-weather days (annual 90th percentile of daily FFDI values) at 38 climate reference sites, and the timeseries in Figure ATM23b shows the increasing trend in the annual cumulative FFDI at Melbourne Airport. A long-term trend is discernible despite significant annual variability (CSIRO & BoM 2014).



Note: Map trends are given in Forest Fire Danger Index points per decade. Larger circles represent larger trends. Filled circles represent trends that are statistically significant. Trends are upward (in red) except for Brisbane airport (in blue).
Source: Bureau of Meteorology

Figure ATM23a Trends in extreme fire-weather days (annual 90th percentile of daily Forest Fire Danger Index values) at 38 climate reference sites

Box ATM3 (continued)

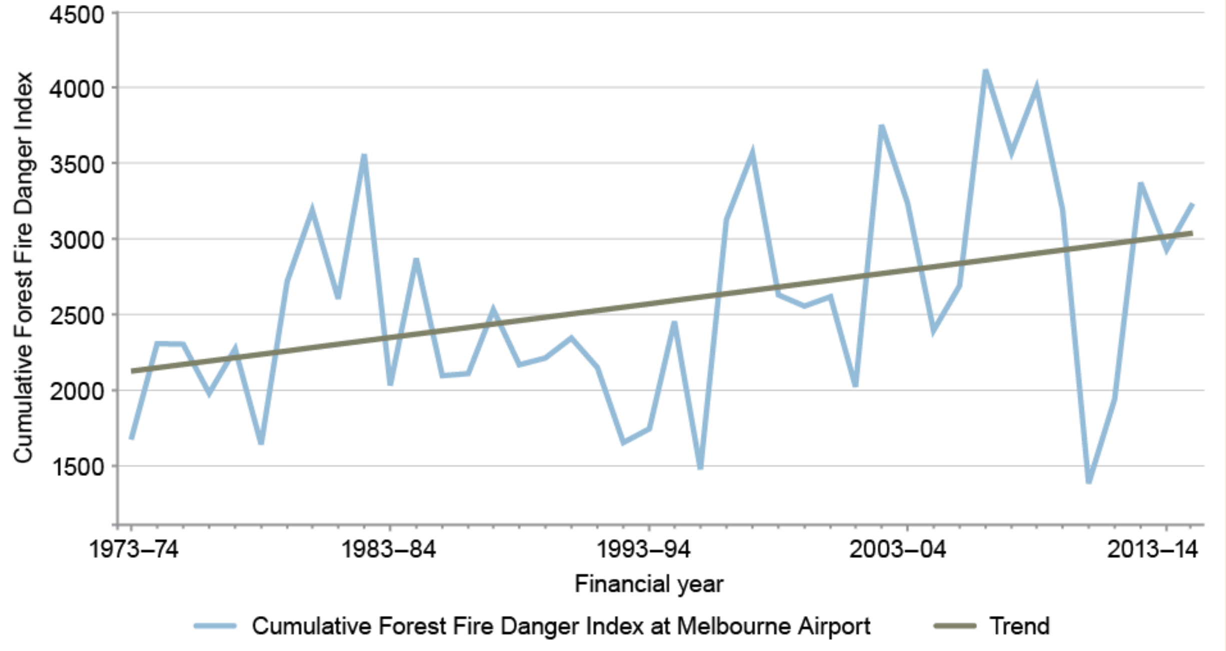


Figure ATM23b Timeseries of the annual cumulative Forest Fire Danger Index at Melbourne Airport

Effectiveness

of management of Australia's climate

At a glance

Climate change is a global problem that will require coordinated international action by all countries. The Paris Agreement, to which 195 countries (including Australia) have agreed, aims to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 °C. As its contribution, the Australian Government has committed to reducing emissions to 26–28 per cent below 2005 levels by 2030.

In the 5 years since SoE 2011, international climate science has advanced significantly. The Intergovernmental Panel on Climate Change published its Fifth Assessment Report in September 2013, confirming that humans have been the dominant cause of warming since the 1950s. A significant amount of Australia's contribution to global and regional understanding of climate change was carried out under the Australian Climate Change Science Program, to which the Australian Government committed $15 million per year between 2011 and 2015. The 26-year program was replaced with the National Environmental Science Programme's Earth System and Climate Change Hub in 2016 at an investment level of $23.9 million across 5 years.

Australian governments have implemented policies to reduce greenhouse gas emissions. Measures include labelling and minimum performance standards for appliances, changes to building codes to drive energy efficiency, and restrictions on land clearing. Both national and state market-based schemes have also been implemented to promote emissions reductions.

Since 2001, the Renewable Energy Target has encouraged the generation of electricity from renewable sources using tradeable certificates that are created by renewable energy generators. The Clean Energy Future package, legislated under the *Clean Energy Act 2011*, saw a cap-and-trade emissions trading scheme that started in July 2012, which included a carbon price covering more than half of Australia's emissions, and the Carbon Farming Initiative, which provided incentives to reduce emissions in the land sector. As part of the Australian Government's Direct Action Plan, the Clean Energy legislation was repealed in 2014 and the Emissions Reduction Fund (ERF) was introduced. The ERF involves crediting, purchasing and safeguarding emissions reductions. The Clean Energy Innovation Fund, announced in March 2016, will provide $1 billion to support emerging clean energy technologies.

Improved energy efficiency can reduce energy demands and is another way to reduce emissions. National strategies—such as minimum energy performance standards and mandatory energy rating labels for appliances, and construction codes, energy rating schemes and disclosure of energy performance for buildings—have aimed to increase energy efficiency. The National Energy Productivity Plan (NEPP), announced in 2015, will now form the overarching framework for improving energy efficiency. The goal of the NEPP is to improve Australia's energy productivity by 40 per cent between 2015 and 2030.

Between December 2012 and June 2014, emissions from the electricity sector decreased in conjunction with a decrease in electricity demand. Emissions from the transport, industrial and agriculture sectors also decreased. By June 2015, emissions from the electricity sector had increased, but demand for electricity had flattened, suggesting an increase in the emissions intensity of delivered electricity. Emissions from the agriculture sector also decreased.

Emissions projections reported in 2016 suggest that Australia is on track to exceeding its emissions reduction target in 2020. However, many of the factors that contributed to the significant downwards revision in the cumulative abatement task are likely to change (e.g. growing seasons may improve; commodity prices may increase), so that the cumulative abatement task may be revised upwards in later projections. In addition, the significant debate about whether the ERF will be as effective as proposed by the Australian Government contributes to uncertainty around the cumulative abatement presented in 2016.

> *Climate science also tells us that warming beyond that (2 °C) threshold is likely to have increasingly severe social, economic and environmental impacts, not least in a dry continent like Australia. Avoiding those impacts will require concerted global actions with all countries—Australia included—shouldering a fair share of the emissions reduction burden: unilateral insouciance is no protection against the encroachment of climate change.* (CCA 2015:2)

Climate change poses serious risks to Australia's population, economy and environment. Without strong action to reduce GHG emissions, the world is likely to warm by 4 °C by 2100 (Sherwood et al. 2014). For Australia, this would mean temperature rises of 3–5 °C in coastal areas and 4–6 °C inland (CCA 2014).

Climate change is fundamentally a global problem—Australia's climate is equally affected by CO_2 emitted in other countries as it is by CO_2 emitted within Australia. Reducing GHG emissions will therefore require coordinated action by all countries, particularly the major emitting countries.

In addition to action to reduce emissions, Australian governments continue to have a key role in climate change adaptation, as outlined in SoE 2011. The role includes:

- supporting scientific research that is unlikely to be undertaken by the private sector (Australian Government)
- providing information to the private sector and the community to encourage and assist adaptation (all levels of government)
- adopting policy settings that facilitate adaptation and a regulatory framework that supports effective market signals (all levels of government, with a particularly critical role for the Australian Government)
- employing policy mechanisms (e.g. land-use planning, building codes, product standards) where short-term market responses may act to restrict longer-term adaptive action (primarily relevant to state and territory governments, but also to the Australian Government for setting minimum energy performance standards and the Building Code of Australia, and to local governments, which play an important role in on-ground implementation)
- fully factoring climate change into planning, resourcing and managing the provision of public goods and services such as public health and safety; emergency services; flood and coastal protection; water supply, drainage and sewerage services; and protection of public lands, parks and reserves, and fisheries and other natural resources (all levels of government, but especially state, territory and local governments).

Understanding and research

In the 5 years since SoE 2011, international climate science has advanced significantly. The IPCC, operating under the United Nations, is the leading international scientific body for the assessment of climate change. Its role is to review, assess and synthesise the latest information on climate change, based on the most recent peer-reviewed literature. AR5, which cited more than 9200 scientific publications and contained contributions from more than 600 authors (Stocker et al. 2013b), confirms (with between 95 and 100 per cent certainty) that humans have been the dominant cause of warming since the 1950s.

Although it is clear that the climate is warming, the complexity of the climate system means that there are still scientific uncertainties about how much the climate will change in the future. In particular, uncertainty exists about:

- future emissions and levels of GHGs, which will be influenced by policies, and population and technology changes
- the precise temperature response to future GHG concentrations, because climate model projections under different GHG emissions scenarios can only estimate temperature increases within a probability range
- how land and ocean carbon sinks will operate in a warmer climate.

With the long-term global investment in climate science (e.g. the large number of climate observation programs and studies), the increased sophistication of Earth system models and increased understanding of some climate processes, the scientific understanding of climate change impacts has increased substantially since 1990. However, to reduce uncertainty further, this investment must continue, because high-quality information about climate change is a core requirement for good adaptation and mitigation policy (Garnaut 2008).

The National Framework for Climate Change Science (established in 2009) outlined the climate science challenges to be addressed in supporting Australia's climate change policy, as well as the capabilities required to deliver this science. The plan for implementation of the framework was established in 2012 and set out a series of key policy questions that, when answered, would deliver national benefit. The plan coordinated the science delivered through the Australian Climate Change Science Program, to which the Australian Government committed $15 million per year between 2011 and 2015. A major achievement of the program has been the development of ACCESS (see Box ATM4). In 2015, the 26-year program was replaced with the National Environmental Science Programme's Earth System and Climate Change Hub ($23.9 million across 5 years).

For the past decade, CSIRO has worked with other groups in the Australian research community, including the Bureau of Meteorology and the Australian Research Council Centre of Excellence for Climate System Science, to develop substantial capabilities and expertise in climate modelling and observations. This has allowed CSIRO to contribute to the global understanding of climatic trends and processes (e.g. see Box ATM5).

In February 2016, CSIRO announced an intention to reduce resourcing in this area. As a consequence of negative national and international reaction to this announcement, the Australian Government and CSIRO subsequently announced the formation of a new climate science centre to be housed within CSIRO that will have a guaranteed base level of support for 10 years.

The Australian Research Council Centre of Excellence for Climate System Science was established in 2011. It is a consortium of 5 Australian universities, and a suite of national and international partners. It will build on and improve existing understanding of the modelling of regional climates to enable enhanced adaptation to, and management of, climate change, particularly in the Australian region. It has strong links with the ACCESS initiative and works in partnership with the National Computational Infrastructure facility.

The National Climate Change Adaptation Research Facility (NCCARF), hosted by Griffith University, Queensland, was established in 2008. Its mandate is to carry out research to support decision-makers as they prepare for, and manage the risks of, climate change. During phase 1, the Australian Government committed a further $9 million for 3 years (2014–17) to phase 2 of NCCARF to address the needs of local government adaptation decision-makers and practitioners in the coastal zone. These groups deal with projected impacts such as more frequent and more intense heatwaves, increasing risk of flooding from rivers and the sea, and increasing coastal erosion.

Planning and strategy

An important role of government is to develop effective policies, implemented through supporting strategies and plans.

Emissions

Significant international action to reduce GHG emissions is now afoot. The international political response to climate change began at the Rio Earth Summit in 1992, and led to the Paris Agreement in 2015, to which 195 countries, including Australia, agreed. This new agreement, under the United Nations Framework Convention on Climate Change, aims to limit the increase in global temperatures to 2 °C above pre-industrial levels, while pursuing efforts to hold the increase to 1.5 °C.

Box ATM4 Australian Community Climate and Earth System Simulator

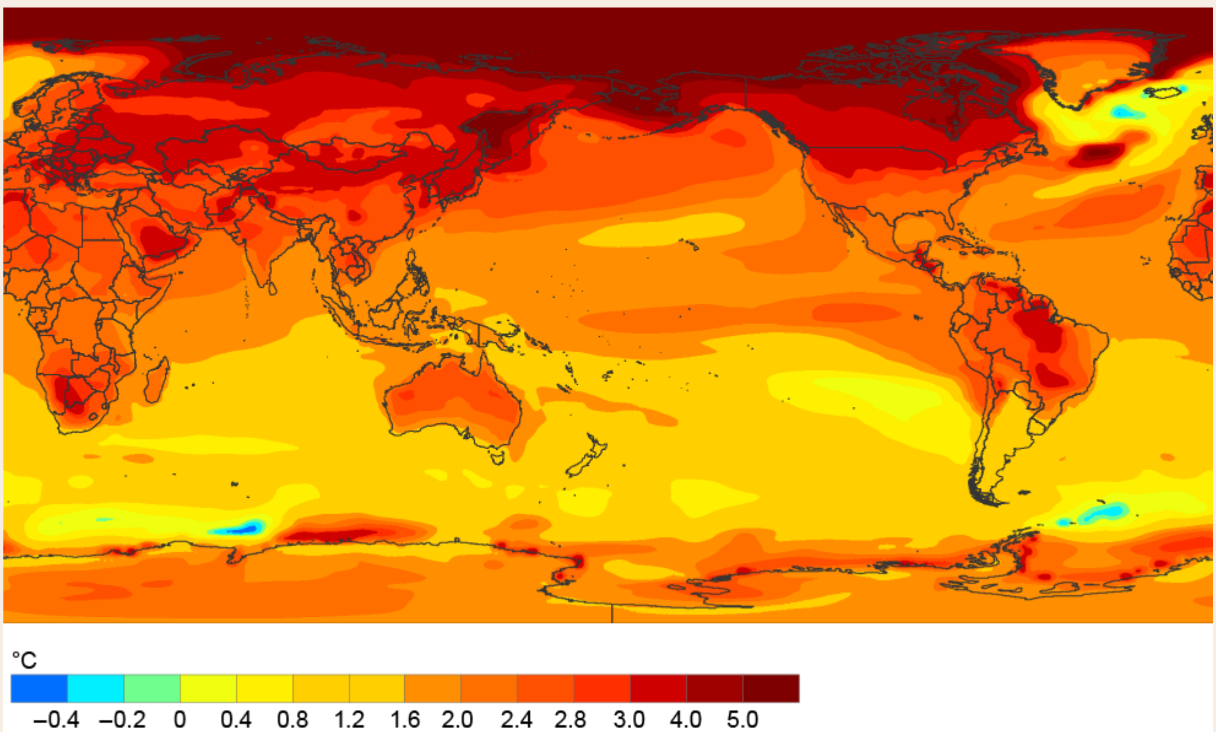
The Australian Community Climate and Earth System Simulator (ACCESS) was developed jointly by the Bureau of Meteorology, CSIRO and Australian universities to provide a national capability to model the Earth climate system on timescales from hours to centuries. Development of ACCESS also involved significant international collaboration, particularly with the United Kingdom Met Office.

ACCESS is a global model that includes all elements of the climate system affecting Australia's weather. It links models of the oceans, atmosphere, sea ice, land surface, global carbon cycle and chemistry, and aerosols to simulate changes in Earth's climate systems. These models are important in understanding past, present and future weather and climate.

ACCESS has improved weather forecasts so that 3-day forecasts are now as accurate as 2-day forecasts were before 2009. This makes for greater certainty in planning and responding to weather events. ACCESS simulations now provide unprecedented detail about fire-weather danger and real-time conditions to support planning and deployment of fire crews and emergency management.

ACCESS simulations rank in the upper level of international climate model simulations and are particularly skillful over Australia, based on simulations of historical climate (Figure ATM24). ACCESS provided Australia's major input to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). This included simulations of the climate of the 20th century, and projections for the 21st century for a range of future greenhouse gas and aerosol concentration scenarios. ACCESS will also provide Australia's major input to the Sixth Assessment Report of the IPCC on the world's climate future.

Development and refinement of ACCESS continue, so that it will meet the climate and weather information needs of government, industry and the community.



Source: CSIRO

Figure ATM24 Global surface air temperature changes, 2071–2100, relative to 1981–2010, using a low-emissions to moderate-emissions scenario

Box ATM5 Cape Grim: monitoring the health of the global atmosphere for 40 years

The Cape Grim Baseline Air Pollution Station (Cape Grim BAPS), established in 1976 to monitor and study global atmospheric composition for trends as a result of human activities and natural variability, celebrated its 40th anniversary in 2016. The station is managed by the Bureau of Meteorology, which partners with CSIRO to manage the science program, in collaboration with the University of Wollongong and the Australian Nuclear Science and Technology Organisation. Cape Grim BAPS is one of 3 premier stations of the World Meteorological Organization Global Atmospheric Watch Program. Located on the north-west tip of Tasmania, Cape Grim BAPS is able to measure 'true background' air—air that is uncontaminated by point sources—when the wind blows in to the south-west sector from across the Southern Ocean.

At Cape Grim, measurements (Figure ATM25) are made of all significant greenhouse gases, ozone depleting substances, aerosols including black carbon, reactive gases including tropospheric ozone, nitrogen oxides, volatile organic compounds, radon (an indicator of recent terrestrial influences), solar radiation, rainfall chemical composition, mercury, and persistent organic pollutants (POPs); and meteorological variables such as wind speed and direction, rainfall, temperature, humidity and air pressure. The Cape Grim Air Archive, initiated by CSIRO in 1978 and carried on by Cape Grim BAPS, is now the world's most important and unique collection of background atmospheric air samples, underpinning many research papers on global and Australian emissions of greenhouse and ozone depleting gases.

Cape Grim data are freely available from major global data archives.[1] They have been widely cited in all 5 international assessments of climate change by the Intergovernmental Panel on Climate Change (1990–2013), in all 10 international assessments of ozone depletion from the United Nations Environment Programme and World Meteorological Organization (1985–2014), in all 4 State of the Climate reports (2010, 2012, 2014, 2015), and in tropospheric ozone assessments.

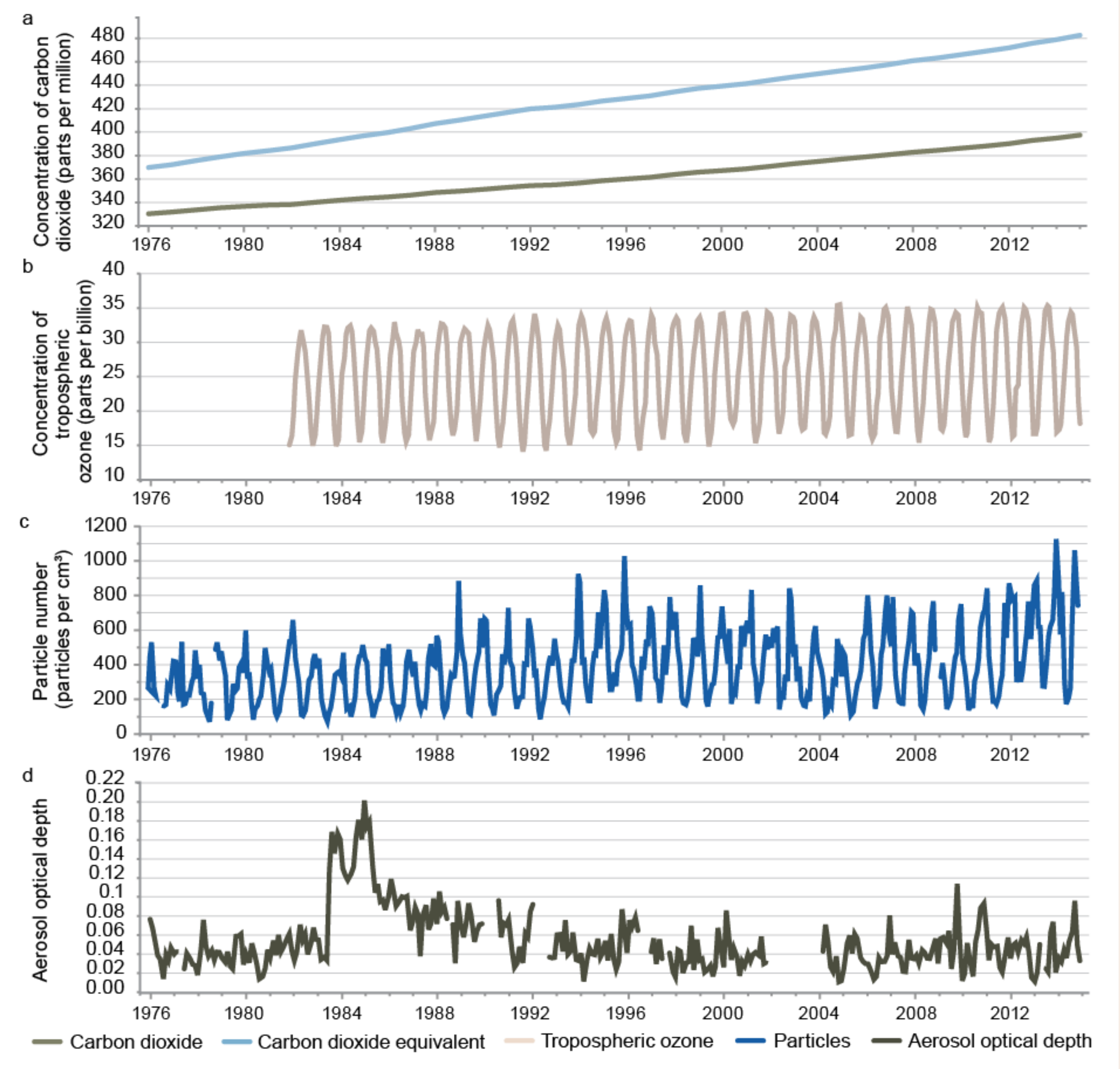
Cape Grim data are also used by the Australian Government to meet international obligations. For example, Cape Grim greenhouse gas data have been used to provide independent verification of components of Australia's National Greenhouse Gas Inventory, which reports Australia's annual emissions to the United Nations Framework Convention on Climate Change; Cape Grim POPs data have been reported to the Stockholm Convention on Persistent Organic Pollutants; and Cape Grim mercury data have been reported to the Minamata Convention on Mercury.

Cape Grim BAPS data have also been used in hundreds of research papers on climate change and atmospheric pollution. Through its work with universities, Cape Grim BAPS is a training ground for the next generation of climate scientists.

1 World Data Centre (WDC) for Greenhouse Gases, WDC for Aerosols, WDC for Reactive Gase

Cape Grim Baseline Air Pollution Station, Tasmania, situated 90 metres above sea level

Box ATM5 (continued)



Note: Carbon dioxide (CO_2) concentrations have shown a 22 per cent increase since 1976. Carbon dioxide equivalent (CO_2-e) concentrations have shown a 33 per cent increase. CO_2-e is a term for describing different greenhouse gases using a common unit. For any quantity and type of greenhouse gas, CO_2-e signifies the amount of CO_2 that would have the equivalent global warming impact. CO_2-e, as presented here, has been calculated using all the significant long-lived greenhouse gases. Surface ozone concentrations show a clear seasonal cycle, with a maximum in winter and a minimum in summer, and an average increase of approximately 0.24 per cent per year since 1982. Particle number concentration shows a clear seasonal cycle of maximum concentrations during summer and minimum concentrations during winter. The aerosol optical depth timeseries shows the impact of the Mount Pinatubo eruption in 1991, as a result of stratospheric transport from the Northern Hemisphere.
Source: CSIRO

Figure ATM25 Timeseries of monthly mean concentrations of (a) carbon dioxide and carbon dioxide equivalent, and (b) tropospheric ozone; (c) monthly median particle number concentration; and (d) monthly median aerosol optical depth at 868 nanometres at Cape Grim under baseline wind conditions

Other international action includes the Montreal Protocol, which is focused on reducing the impact of ozone depleting substances, many of which are also significant GHGs. The phase-out of ozone depleting substances under the Montreal Protocol is estimated to have delayed climate forcing by up to 12 years (Distefano 2008).

The impacts of climate change will only be minimised in Australia if the international community achieves its GHG goals.

As its contribution to the international effort, the Australian Government has committed to domestic emissions reduction targets determined through consultation and detailed analysis. It has committed to reducing emissions to 26–28 per cent below 2005 levels by 2030, a target that the Australian Government believes is in step with the efforts of other comparable nations. However, this target is lower than that recommended by the Climate Change Authority of 40–60 per cent below 2000 levels by 2030 to meet an emissions budget of 10.1 billion tonnes of GHGs for 2013–50 (CCA 2015).

Australian governments have been implementing policies to reduce GHG emissions for more than 2 decades (see Box ATM6). Measures include labelling and minimum performance standards for appliances, changes to building codes to drive energy efficiency, and restrictions on land clearing. A range of market-based schemes have been implemented to promote emissions reductions, including national schemes such as the Renewable Energy Target and state-based schemes. The Australian Government is also committed to supporting developing countries to build climate change resilience and reduce emissions through the Australian aid program.

Renewable Energy Target

The Renewable Energy Target (RET) is a scheme designed to reduce GHG emissions in the electricity sector and encourage the generation of electricity from renewable sources. This is done by guaranteeing a market for additional renewable energy using tradeable certificates that are created by renewable energy generators (such as wind farms) and owners of small-scale renewable energy systems (such as solar photovoltaic systems).

The RET has contributed to renewable energy generation since 2001 (Table ATM1). Between 2001 and 2013, Australia's renewable electricity capacity nearly doubled, from 17,800 gigawatt hours (GWh) in 2001–02 to about 32,500 GWh in 2012–13 (CCA 2012). About 2 million households have installed rooftop solar panels, and, in 2014, the cost of solar photovoltaic installation was one-sixth the price it was a decade earlier (APVI 2015, Australian Government 2015a). Between 2001 and 2012, the RET reduced emissions by an estimated 22.5 $MtCO_2$-e (SKM 2012). Because of decreases in energy demands and declining forecast demand in 2020, the current target (introduced in 2015) is expected to increase the share of renewables to around 23.5 per cent of Australia's electricity in 2020 (Australian Government 2015a).

Table ATM1 Renewable energy targets, 2001–15

Year	Changes to renewable energy targets
2001	9500 GWh by 2010
2009	45,000 GWh by 2020
2011	The Renewable Energy Target was split into 2 schemes: • The Large-scale Renewable Energy Target (LRET) supports large-scale projects. The LRET has annual fixed targets and a 2020 target of 41,000 GWh. • The Small-scale Renewable Energy Scheme (SRES) supports the installation of small-scale systems. The SRES has an implicit target of 4000 GWh, but is uncapped. The Climate Change Authority estimated that it may result in about 11,000 GWh of generation in 2020 (CCA 2012)
2015	LRET: 33,000 GWh by 2020. Native forest wood waste was reinstated as an eligible source of renewable energy, subject to the conditions that were in place before 2011

GWh = gigawatt hour

Box ATM6 Summary of Australia's climate change legislation and authorities

The *Clean Energy Act 2011* established an Australian emissions trading scheme, to be preceded by a 3-year period of fixed carbon pricing designed to reduce carbon dioxide emissions. However, the Clean Energy Act was repealed by the *Clean Energy Legislation (Carbon Tax Repeal) Act 2014*.

The *Carbon Credits (Carbon Farming Initiative) Act 2011* allows Australian carbon credit units to be issued in relation to an eligible offsets project. The Act was amended in 2014 to allow the Clean Energy Regulator (CER) to purchase emissions reductions through a reverse auction system as part of the Emissions Reduction Fund (ERF).

The CER is a statutory authority established in 2012 under the *Climate Energy Regulator Act 2011*. The CER administers responsibilities in relation to the Renewable Energy Target, the crediting and purchasing of abatement under the ERF, the National Greenhouse and Energy Reporting Scheme, and the Australian National Registry of Emissions Units.

The Climate Change Authority (CCA) is a statutory authority established in 2012 under the *Climate Change Authority Act 2011*. The CCA conducts climate change research and periodic reviews of climate change measures, and reports on Australia's progress in meeting national emissions reductions targets. Parliament rejected an attempt to repeal the Climate Change Authority Act (Climate Change Authority [Abolition] Bill 2013).

The Clean Energy Finance Corporation (CEFC) is a statutory authority established in 2012 under the *Clean Energy Finance Corporation Act 2011*. The CECF facilitates increased flows of finance into the low-emissions energy sector through investment in renewable energy, energy efficiency and low-emissions technologies, administering $10 billion (until 2018) of legislated funding. The CEFC co-finances clean energy projects with the private sector, working with the market to build industry capacity. Parliament rejected an attempt to repeal the Clean Energy Finance Corporation Act (Clean Energy Finance Corporation Act [Abolition] Bill 2013).

The Australian Renewable Energy Agency (ARENA) is a statutory authority established in 2012 under the *Australian Renewable Energy Agency Act 2011*. ARENA aims to improve the competitiveness of renewable energy technologies and increase the supply of renewable energy in Australia. ARENA is responsible for administering around $2.4 billion (until 2022) of legislated funding for research into, and development, demonstration, deployment and commercialisation of, renewable energy and related technologies; and the storage and sharing of knowledge and information about renewable energy technologies.

Clean Energy Future

In 2011, the Clean Energy Future package was legislated (*Clean Energy Act 2011*) to create a carbon-pricing mechanism (a cap-and-trade emissions trading scheme). This commenced in July 2012. The package included a carbon price, which covered more than half of Australia's emissions, and the Carbon Farming Initiative, which was a voluntary scheme that provided incentives to reduce emissions in the land sector.

The carbon-pricing mechanism required Australia's largest GHG emitters to obtain and submit eligible carbon credit units for each tonne of CO_2-e they emitted, thus creating an incentive to reduce those emissions. The carbon-pricing mechanism covered emissions from electricity generation, direct combustion, landfills, wastewater, industrial processes and fugitives. The carbon-pricing mechanism had a 3-year fixed-price period (1 July 2012 to 30 June 2015), during which the price of Australian carbon units started at $23 per tonne of CO_2-e and rose by 2.5 per cent per year. After this period, the price was to be capped at a level set by parliament, 5 years in advance (CCA 2014).

Decreasing emissions from the electricity sector (the largest source of emissions in the national inventory) were reported between December 2012 and June 2014 (DIICCSRTE 2012; DoE 2013, 2014b). Attribution of this trend to the effectiveness of the carbon-pricing mechanism is difficult, because electricity demand during this time had also decreased. However, in June 2015, emissions from the electricity sector had increased while demand for electricity had flattened, suggesting an increase in the emissions intensity of delivered electricity (DoE 2015a). Between December 2012 and June 2014, emissions from the transport, industrial and agriculture sectors also decreased (DIICCSRTE 2012; DoE 2013, 2014b), whereas in 2015 only emissions from the agriculture sector had decreased (DoE 2015a).

Emissions Reduction Fund

As part of the Australian Government's Direct Action Plan, the Clean Energy legislation, with its carbon-pricing mechanism, was repealed in 2014, and the Emissions Reduction Fund (ERF) was introduced. The ERF involves crediting, purchasing and safeguarding emissions reductions.

Crediting involves determining an amount of emissions reductions delivered by an emissions reduction project. The Clean Energy Regulator then purchases emissions reductions through a reverse auction system (i.e. the Clean Energy Regulator buys GHG emissions reductions at lowest prices through a competitive tender process). The measurement used for the ERF auction is the Australian carbon credit unit (ACCU), where 1 ACCU represents 1 tonne of GHG emissions reduced.

A Safeguard Mechanism was also developed to ensure that emissions reductions achieved through the crediting and purchasing elements of the ERF are not offset by significant increases in emissions above baseline levels elsewhere in the economy. Baseline levels are defined as the highest level of emissions for a facility reported to the National Greenhouse and Energy Reporting Scheme between 2009 and 2014. The Safeguard Mechanism came into force on 1 July 2016 and will apply to around 140 large businesses that have facilities with direct emissions of more than 100,000 tonnes of CO_2-e per year (i.e. businesses that account for half of Australia's emissions). Although this mechanism is very important to ensure that emissions from these large facilities do not increase under the ERF, it will do little to reduce their emissions. The success of the ERF may be influenced by the extent to which these large emitters participate in the purchasing element of the ERF.

Two reverse auctions for the ERF were held in 2015, which saw the Clean Energy Regulator purchase, using approximately half of the money available in

Wind turbines at Codrington Wind Farm, near Yambuk in Victoria, generating electricity on the coastal headlands at sunset
Photo by Arthur Mostead

the fund ($1.22 billion of $2.55 billion), 93 million tonnes of abatement from 275 projects at an average price of $13.10 per tonne. Most of these projects involve rural activities (i.e. carbon credits are generated by paying to stop the destruction of native vegetation, so effectively could be achieved at no cost through regulatory intervention). Some debate exists about whether the funds available to the ERF will be sufficient to reach emissions reductions required to meet the Kyoto Protocol 2020 target. Clarke et al. (2014) used a computable general equilibrium model to estimate that the budget allocated for the ERF provides about 50 per cent of that required to meet Australia's GHG abatement commitments. Assuming the same average price per tonne achieved during the 2015 reverse auctions for future sales, the fund will be able to purchase another 101 million tonnes of emissions. This will be 44 million tonnes (about 19 per cent) short of Australia's 5 per cent target (Christoff 2015).

However, the *Tracking to 2020* (DoE 2015b) update on emissions projections estimates a contribution by the ERF of 92 $MtCO_2$-e to the cumulative abatement task required to meet the Kyoto Protocol 2020 target (in total, reduced from 236 $MtCO_2$-e to –28 $MtCO_2$-e in this projection). Under this projection, the target will be exceeded by 28 $MtCO_2$-e. If we consider that the ERF contributes significantly (one-third) to this projected reduction, it will be important to monitor the effectiveness of the ERF as the target date approaches and act accordingly if the need arises.

Other competitive tender auctions for environmental management have been successful in Australia. The New South Wales Greenhouse Gas Reduction Scheme ran from January 2003 to June 2012, and was the first mandatory GHG emissions trading scheme for the electricity sector in the world. It demonstrated that a market-based mechanism could be used to achieve environmental objectives at a relatively low cost to consumers and government. It stimulated a wide range of accredited abatement projects, creating 144 million abatement certificates, which represented around 144 $MtCO_2$-e of GHG abatement (IPART 2013). BushTender was an on-farm biodiversity conservation procurement auction that was run in Victoria between 2001 and 2012. BushTender demonstrated value for money for the state and Australian governments (Stoneham et al. 2003), and resulted in the management and protection of more than 35,251 hectares of native vegetation.

Clean Energy Innovation Fund

The Clean Energy Innovation Fund, announced in March 2016, will provide $1 billion to support emerging clean energy technologies in the move from demonstration to commercial deployment. The fund will be jointly managed by the Australian Renewable Energy Agency and the Clean Energy Finance Corporation.

Energy efficiency

Several Australian Government programs target improvements in energy efficiencies. Energy efficiency will contribute to a reduction in energy demands and thus emission levels. The National Energy Productivity Plan (NEPP) forms the overarching framework for improving energy efficiency, and sets the goal to improve Australia's energy productivity by 40 per cent between 2015 and 2030 (COAG Energy Council 2015). The NEPP includes a number of measures, such as options to improve vehicle efficiency, and promote innovation and competitive energy markets.

Mandatory minimum energy performance standards and mandatory energy rating labels have been the main policy tools used to improve the energy efficiency of appliances and equipment in the residential, commercial and industrial sectors since 1986. Meanwhile, the Australian Government Department of Industry has administered a number of programs designed to improve energy efficiency in buildings, including construction codes, energy rating schemes and disclosure of energy performance. The Community Energy Efficiency Program is providing $106 million to co-fund energy efficiency upgrades to local council and community facilities, and the Low Income Energy Efficiency Program has provided $55 million across trial approaches to reduce the energy costs of low-income households.

The NEPP will also target vehicle fuel efficiency. A ministerial forum that investigated vehicle emissions standards and vehicle testing arrangements reported in 2016. This initiative has links with measures under the National Clean Air Agreement to reduce air pollution. In addition, a program funded through the Clean Energy Finance Corporation ($50 million) will provide incentives for fleet purchases with low-emissions vehicles.

Other programs include:

- 20 Million Trees, which aims to plant 20 million trees by 2020 to re-establish green corridors and urban forests in urban and regional Australia
- the Solar Towns Program, which will provide $2.1 million to community organisations to support the installation of solar photovoltaic panels and solar hot water systems in buildings
- the Low Emissions Technology Roadmap, which will help identify opportunities for, and barriers to, research, development and take-up of new and emerging low-emissions technologies across Australia
- low-emissions fossil fuel technology programs, which target technologies to develop low-emissions fossil fuel technologies, including operations of the Australian Government Department of Industry
- the National Carbon Offset Standard, which provides a benchmark for businesses and other organisations voluntarily seeking to be carbon neutral for their operations, products, services or events
- the Carbon Neutral Program, which allows organisations, products, services and events to be certified as carbon neutral against the National Carbon Offset Standard
- Energy Efficiency Information programs, which develop a range of information, capacity-building and knowledge-sharing web resources, including the Energy Efficiency Exchange, Your Energy Savings and Your Home websites.

In 2015, the Australian Government also released the National Climate Resilience and Adaptation Strategy (Australian Government 2015b) to articulate how Australia is managing the risks of a variable and changing climate.

Role and coordination of different levels of government

The 3 levels of government in Australia all contribute to the Australian community's ability to mitigate and adapt to climate change. All levels are responsible for managing risks to public infrastructure and the environment, delivering government services, and creating the institutional, market and regulatory environment that supports and promotes resilience and action among individuals and groups.

One of the most important roles of governments is to ensure that society has the information required to make informed decisions and adjust behaviours in response to climate risks.

As discussed previously, the Australian Government is responsible for an overarching policy implemented through a range of strategies and plans, and plays a major part in providing climate science and information. The government is responsible for maintaining a strong, flexible economy and well-targeted safety net to ensure that climate change does not disproportionately affect vulnerable groups. It works to ensure effective natural resource management across land, water, marine and coral reef systems, and considers the economy-wide implications of actions determined at local and regional levels (Australian Government 2015b).

Through planning laws and investments in public infrastructure, state and territory governments lead adaptation actions. They ensure that regulatory and market frameworks are in place that ensure accurate and regionally appropriate information, and delivery of adaptation responses within their jurisdiction. This includes delivery of essential services such as emergency services, environmental protection, and planning and transport. Table ATM2 lists examples of key climate change policies and strategies established at the state and territory level.

Local governments are at the forefront in responding to the impacts of climate change. They are well positioned to inform the state, territory and Australian governments about the on-ground needs of local and regional communities, to communicate directly with those communities, and to respond to local changes. They ensure that particular local circumstances are considered in the overall adaptation response and involve the local community directly in efforts to facilitate effective change.

Coordination between Australian, state and territory governments occurs though the Council of Australian Governments (COAG). In 2013, COAG articulated the roles and responsibilities of different levels of government for climate change adaptation (Australian Government 2013). Under the COAG Energy Council's work program, the NEPP is an example of bringing together new and existing measures from across governments and industry to improve energy efficiency, and thus reduce emissions associated with energy production.

Collaboration between state, territory and local governments is also important to successful climate change mitigation and adaptation. The Victorian Government has signed a memorandum of understanding with 79 local councils to promote this collaboration. Council Connections is a peer-to-peer learning program for local government practitioners who are undertaking work in the adaptation field. In Queensland, the Coastal Hazards Adaptation Program (QCoast2100) supports coastal councils in identifying coastal hazards and climate change risks, and in the decision-making and implementation phases.

Climate change will have significant impacts on urban centres around the world, prompting the formation of the C40 Cities Climate Leadership Group, of which Melbourne and Sydney metropolitan councils are members. C40 is a network of almost 90 of the world's megacities that are taking action to reduce GHGs.

Table ATM2 State and territory policies and strategies

State/territory	Policy or strategy
Australian Capital Territory	• *Climate Change and Greenhouse Gas Reduction Act 2010* • Targets including zero net greenhouse gas emissions by 2060, 40% reduction in 1990 levels by 2020 and 80% reduction by 2050 • In 2013, addition of a renewable energy target of 90% by 2020 • *Energy Efficiency (Cost of Living) Improvement Act 2012* • Action Plan 2 (2012)—the ACT's second climate change strategy and action plan, which is a strategy to support the vision that, by 2060, Canberra will be a sustainable and carbon-neutral city. Reviewed in 2015, and a new action plan for 2017–20 is to be developed • ACT Planning Strategy, in which the urban structure is supported by public transport and active travel (e.g. walking and cycling) • Transport for Canberra and Light Rail Master Plan • ACT Nature Conservation Strategy 2013–23, which integrates and extends conservation efforts to provide the best chance for natural ecosystems to adapt to expected longer-term shifts in climate • ACT Water Strategy, which includes actions to improve water security and water quality • ACT Waste Management Strategy 2011–25, which aims to achieve full resource recovery and a carbon-neutral waste sector • *Adapting to a changing climate: directions for the ACT* (2014)—a directions paper

Table ATM2 (continued)

State/territory	Policy or strategy
New South Wales	• Climate Change Impacts and Adaptation—Knowledge Strategy 2013–17 • NSW 2021, which sets goals and targets that support practical action to tackle climate change • NSW Renewable Energy Action Plan, which has as its target 20% renewable energy by 2020 • NSW Energy Efficiency Action Plan, which aims for annual energy savings of 16,000 gigawatt hours by 2020 and for low-income households to reduce their energy use by up to 20% by June 2014 • NSW Long Term Transport Master Plan, which aims to increase walking and cycling • Draft Metropolitan Strategy for Sydney, which is a planning policy to encourage job growth in centres close to where people live and to provide access by public transport • NSW Climate Change Council, which provides independent, expert advice to the Office of Environment and Heritage on matters relevant to the NSW Government's response to climate change • Energy Savings Scheme, which aims to reduces electricity consumption in NSW by creating financial incentives for organisations to invest in energy savings projects
Northern Territory	• Northern Territory Climate Change Policy 2009 • *Roadmap to renewables* report to be presented to government in 2017, which will set out how the 2030 target of 50% renewable energy will be met • City of Darwin's Climate Change Policy and subsequent Climate Change Action Plan 2011–2020, which outline goals for government and the community
Queensland	• A Solar Future, which sets targets, including: – 1 million solar rooftops by 2020 – investigating a 50% renewable energy target for 2030 – trialling a 40 megawatt renewable energy reverse auction • Queensland Climate Adaptation Strategy, which supports the development and implementation of the strategy with 29 partners from local government, business, industry, and community and environmental representatives • Coastal Hazards Adaptation Program, which supports coastal councils to identify coastal hazards and climate change risks, and in the decision-making and implementation phases
South Australia	• South Australia's Climate Change Strategy 2015–2050, released in 2015, which targets net zero emissions by 2050 • South Australia's Strategic Plan, which includes Target 64: 33% renewable energy target by 2020 (which has already been exceeded). A new target was set in 2014 of 50% renewable energy by 2020. Also includes Target 66: limiting the carbon intensity of total South Australian electricity generation to 0.5 tonnes of carbon dioxide per megawatt hour by 2020 • *Carbon neutral Adelaide: a shared vision for the world's first carbon neutral city*, which was released in 2015 • *Prospering in changing climate: a climate change adaptation framework for South Australia*, which was released in 2012 and includes an action plan for 2012–17 • Retailer Energy Efficiency Scheme, which encourages larger energy providers to help households and businesses save energy through energy audits and energy efficiency activities

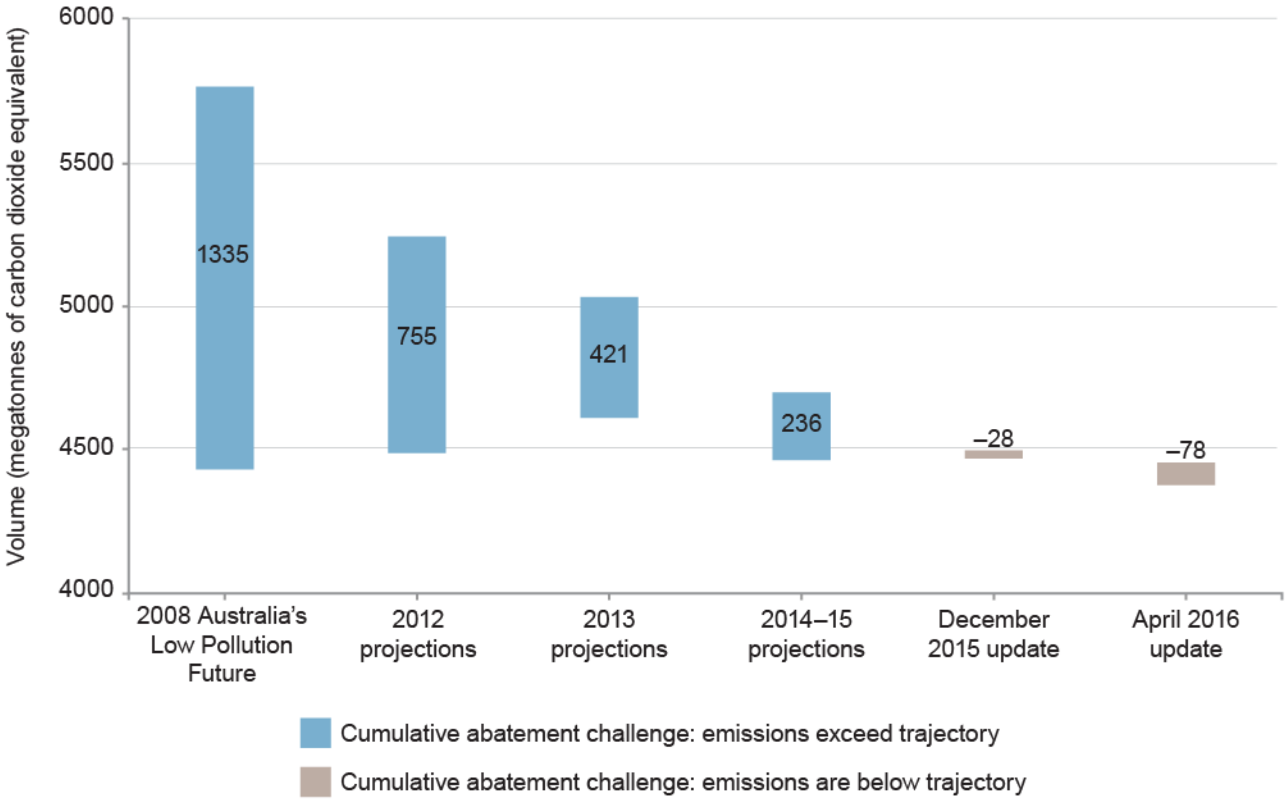
Table ATM2 (continued)

State/territory	Policy or strategy
Tasmania	• *Climate Change (State Action) Act 2008*, which has an emissions reduction target of 60% below 1990 levels by 2020; this target has already been surpassed and is being reviewed in 2016 • *Embracing the climate challenge: Tasmania's draft climate change action plan 2016–21*, in which the Tasmanian Government is currently seeking public input on how to achieve its aims
Victoria	• Victorian Climate Change Adaptation Plan 2013, which sets out how the Victorian Government is managing climate risks. It highlights that effective climate change adaptation requires government, businesses and the community to work together • *Building a climate-resilient Victoria: Victorian climate change adaptation progress report 2014*, which reports on progress towards the 2013 plan • Climate change adaptation memorandum of understanding between the Victorian Government and 79 partners from local government, September 2014 • Independent review of the *Victorian Climate Change Act 2010* in 2015; this report is being prepared • Victorian Energy Efficiency Target scheme, which enables accredited businesses to offer discounts and special offers on selected energy-saving products and appliances installed in homes, businesses and other nonresidential premises • Victorian Climate Change Grants 2015, which assist local government to deal with the most vulnerable local sectors in adapting to climate change
Western Australia	• *Adapting to our changing climate in 2012*, which outlines key climate change challenges and establishes a high-level strategic framework for agencies to develop responses to climate change adaptation for implementation in relevant sectors • Low Emissions Energy Development Fund, which supports innovative technology projects at the commercial demonstration, commercialisation and local adaptation stages in Western Australia

Management outputs and outcomes

Reductions in GHG emissions are essential to minimise the amount of global warming and associated impacts. The projected efficacy of the various policies, programs and actions put in place by governments to meet emissions reduction targets can be summarised by emissions projections, which the Australian Government reports on approximately once per year.

The cumulative abatement challenge describes the gap between expected emissions and the cumulative emissions during 2013–20 allowed under our Kyoto 2020 target, calculated using protocols established under internationally agreed rules. Figure ATM26 shows Australia's cumulative abatement challenge as projected over time and demonstrates that the challenge has fallen significantly since 2008. This long-term decline can be attributed to the Australian economy becoming less emissions intensive, the revision and improvement of international carbon accounting, and the updates to emissions outlooks.



Source: DoE (2016)

Figure ATM26 Cumulative abatement challenge: cumulative emissions (2013–20) minus trajectory (2013–20)

Tracking to 2020—April 2016 update (DoE 2016) indicates that Australia is expected to surpass its 2020 target by 78 $MtCO_2$-e. This follows from the projection released in March 2015, when the task was estimated as 236 $MtCO_2$-e. The significant downwards revision in the task in those 12 months was the result of:

- factoring in emissions reductions expected from the RET, the ERF and the Waste Industry Protocol (EpE Working Group 2013)[3]
- an improved emissions outlook driven by slower than previously expected growth in the agriculture sector (because of ongoing poor seasonal conditions), the liquefied natural gas and coalmining industries (because of lower commodity prices), and land clearing.

Many of the factors that have contributed to the significant downwards revision in the cumulative abatement task are likely to change (e.g. growing seasons may improve; commodity prices may increase). Hence, the cumulative abatement task may be revised upwards in later projections. In addition, the significant debate about whether the ERF will be as effective as proposed by the Australian Government (discussed under Emissions Reduction Fund) also contributes to uncertainty around the cumulative abatement task presented in *Tracking to 2020*.

3 Outlines changes to the way emissions from landfill are calculated.

Assessment summary 2

Effectiveness of climate change management

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Greenhouse gases and climate change				
Understanding of context: Good understanding of broad processes, and improving confidence in modelling projections at both national and regional scales. National greenhouse gas emissions reporting system is improved	Partially effective ↗	●	●	◆
Planning: More ambitious target (26–28% below 2005 levels by 2030) set after the Paris Agreement Significant changes in strategies and planning during this period, with establishment of several policy tools in 2011 that were removed or repealed by 2013 Strategic planning at state level significantly improved	Effective —	●	●	◆
Inputs: Around $13.5 billion committed to climate change initiatives by the Australian Government Funds available to support climate science at both national and state levels have been significantly reduced Resources applied by states and territories to mitigation and adaptation programs have been significantly reduced	Effective —	●	●	◆
Processes: Governance remains complex, with 3 tiers of government involved Coordination of national, and state and territory programs under Council of Australian Governments actions have progressed (e.g. National Energy Productivity Plan), and coordination between state and local governments has improved	Effective ↗	●	●	◆
Outputs and outcomes: Current and projected levels of success of national, state and territory abatement programs suggest targets will be achieved Some states have achieved targets already. Australia appears on track to achieve the national 2020 target of a 5% reduction in greenhouse gas emissions below 2000 levels, although there is some debate about this Methodologies used to project attainment of targets appear to be consistent with international guidelines adopted by the United Nations Framework Convention on Climate Change	Effective ?	●	●	◆

Assessment summary 2 (continued)

Recent trends	Confidence	Comparability
↗ Improving	● **Adequate:** Adequate high-quality evidence **and** high level of consensus	◆ **Comparable:** Grade and trend are comparable to the previous assessment
↙ Deteriorating	◕ **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus	⬙ **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
— Stable	◒ **Limited:** Limited evidence **or** limited consensus	◇ **Not comparable:** Grade and trend are not comparable to the previous assessment
? Unclear	◔ **Very limited:** Limited evidence **and** limited consensus	**X** **Not previously assessed**
	○ **Low:** Evidence and consensus too low to make an assessment	

Management context
(understanding of environmental issues; adequacy of regulatory control mechanisms and policy coverage)

Elements of management effectiveness and assessment criteria	Grades
Understanding of context Decision-makers and environmental managers have a good understanding of: • environmental and socio-economic significance of environmental values, including ecosystem functions and cultural importance • current and emerging threats to values. Environmental considerations and information have a significant impact on national policy decisions across the broad range of government responsibilities	**Very effective:** Understanding of environmental and cultural systems, and factors affecting them is good for most management issues **Effective:** Understanding of environmental and cultural systems, and factors affecting them is generally good, but there is some variability across management issues **Partially effective:** Understanding of environmental and cultural systems, and factors affecting them is only fair for most management issues **Ineffective:** Understanding of environmental and cultural systems, and factors affecting them is poor for most management issues
Planning Policies and plans are in place that provide clarity on: • objectives for management actions that address major pressures and risks to environmental values • roles and responsibilities for managing environmental issues • operational procedures, and a framework for integration and consistency of planning and management across sectors and jurisdictions	**Very effective:** Effective legislation, policies and plans are in place for addressing all or most significant issues. Policies and plans clearly establish management objectives and operations targeted at major risks. Responsibility for managing issues is clearly and appropriately allocated **Effective**: Effective legislation, policies and plans are in place, and management responsibilities are allocated appropriately, for addressing many significant issues. Policies and plans clearly establish management objectives and priorities for addressing major risks, but may not specify implementation procedures **Partially effective:** Legislation, policies and planning systems are deficient, and/or there is lack of clarity about who has management responsibility, for a number of significant issues **Ineffective:** Legislation, policies and planning systems have not been developed to address significant issues

Assessment summary 2 (continued)

Management capacity (adequacy of resources, appropriateness of governance arrangements and efficiency of management processes)	
Elements of management effectiveness and assessment criteria	**Grades**
Inputs Resources are available to implement plans and policies, including: • financial resources • human resources • information	**Very effective:** Financial and staffing resources are largely adequate to address management issues. Biophysical and socio-economic information is available to inform management decisions **Effective:** Financial and staffing resources are mostly adequate to address management issues, but may not be secure. Biophysical and socio-economic information is available to inform decisions, although there may be deficiencies in some areas **Partially effective:** Financial and staffing resources are unable to address management issues in some important areas. Biophysical and socio-economic information is available to inform management decisions, although there are significant deficiencies in some areas **Ineffective:** Financial and staffing resources are unable to address management issues in many areas. Biophysical and socio-economic information to support decisions is deficient in many areas
Processes A governance system is in place that provides for: • appropriate stakeholder engagement in decisions and implementation of management activities • adaptive management for longer-term initiatives • transparency and accountability	**Very effective:** Well-designed management systems are being implemented for effective delivery of planned management actions, including clear governance arrangements, appropriate stakeholder engagement, active adaptive management and adequate reporting against goals **Effective:** Well-designed management systems are in place, but are not yet being fully implemented **Partially effective:** Management systems provide some guidance, but are not consistently delivering around implementation of management actions, stakeholder engagement, adaptive management or reporting **Ineffective:** Adequate management systems are not in place. Lack of consistency and integration of management activities across jurisdictions is a problem for many issues

Assessment summary 2 (continued)

Achievements (delivery of expected products, services and impacts)	
Elements of management effectiveness and assessment criteria	**Grades**
Outputs Management objectives are being met with regard to: • timely delivery of products and services • reduction of current pressures and emerging risks to environmental values	**Very effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are being demonstrably reduced **Effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are understood, and measures are in place to manage them **Partially effective:** Management responses are progressing and showing signs of achieving some objectives. Targeted threats are understood, and measures are being developed to manage them **Ineffective:** Management responses are not progressing in accordance with planned programs (significant delays or incomplete actions), or the actions undertaken are not achieving their objectives. Threats are not actively being addressed
Outcomes Management objectives are being met with regard to improvements in resilience of environmental values	**Very effective:** Resilience of environmental values is being maintained or improving. Values are considered secure against known threats **Effective:** Resilience of environmental values is improving, but threats remain as significant factors affecting environmental systems **Partially effective:** The expected impacts of management measures on improving resilience of environmental values are yet to be seen. Managed threats remain as significant factors influencing environmental systems **Ineffective:** Resilience of environmental values is still low or continuing to decline. Unmitigated threats remain as significant factors influencing environmental systems

Resilience

of Australia's climate

At a glance

Our planet is somewhat resilient to increasing carbon dioxide (CO_2) levels because atmospheric CO_2 is absorbed by the oceans. During recent decades, the oceans have taken up approximately 25 per cent of the annual anthropogenic CO_2 emissions to the atmosphere. However, the capacity of the oceans to absorb CO_2 appears to be limited, because the absorbed CO_2 is making our oceans more acidic, with consequent environmental impacts.

The lag in the system is significant. Modelled projections show that, if CO_2 levels are ramped down to pre-industrial concentrations, surface air temperature and sea level change exhibit a substantial timelag relative to atmospheric CO_2—in models, even 900 years after CO_2 was restored to pre-industrial levels, surface air temperature and sea level were considerably higher than under pre-industrial conditions.

The palaeorecord confirms this modelling. In the Palaeocene–Eocene Thermal Maximum era (56 million years ago), CO_2 was being released to the atmosphere at one-tenth of the rate of today. The era resulted in a rapid onset of 6 °C global warming, followed by a gradual recovery during 150,000 years. Although many species ultimately survived, the perturbations to the environment of this warming persisted for tens of thousands of years.

The interaction between the environment and society means that resilience of the physical environment and human societies must be considered together.

Resilience of a society to climate change is dependent on the sensitivity of the society to change and its capacity to adapt to change. Climate-resilient pathways may involve significant transformations in political, economic and socio-technical systems. The success of climate-resilient pathways is linked to the success of climate change mitigation (i.e. as problems become unmanageable, future options for climate-resilient pathways may be reduced).

Climate change will result in location-specific vulnerabilities, and people who are disadvantaged are most sensitive to climate change. However, some regions may benefit from climate change (e.g. warmer temperatures will result in reduced energy demand for winter heating and reduced winter mortality in cooler climates, including southern Australia).

Within Australia, Indigenous communities may be particularly vulnerable to climate change impacts, particularly those people who live in remote interior or low-lying coastal areas, or who rely on natural resources for their livelihoods. However, adaptation and mitigation to climate change may offer opportunities for Indigenous communities through engagement with environmental management.

It is important that vulnerabilities in social resilience are reflected in national and international policies aimed at adapting to climate change.

Resilience is the capacity of the environment to retain or recover the same structure and functions after experiencing shocks or disturbances. The interaction between the environment and society means that resilience of the physical environment and human societies cannot be considered separately. Hence, in this section, we consider the resilience of our climate system itself, and the resilience of our environment and society to climate change.

Resilience of our climate

The ability of the climate system to recover from changes to the composition of the atmosphere (particularly increasing CO_2 concentrations) is complicated by the fact that the removal of CO_2 from the atmosphere involves several processes that occur across different timescales. Mixing with surface ocean waters and reacting with dissolved carbonate ions occurs across 10–100 years, transport and mixing throughout the deep ocean between 100 and 1000 years, the reaction of CO_2 with deep-sea carbonate sediments across 100–10,000 years, and long-term neutralisation by weathering of carbonate and silicate minerals on the continents from 10,000 to 1 million years (Zeebe & Zachos 2013).

As part of an intercomparison project of Earth System Models of Intermediate Complexity, Zickfeld et al. (2013) investigated the extent to which climate change is reversible on human timescales. Using idealised scenarios and 4 Representative Concentration Pathways for GHGs and aerosols for the year 3000, they simulated the change in the concentration of atmospheric CO_2, surface air temperature and sea level if CO_2 emissions ceased at 3000 or underwent a linear decrease to pre-industrial concentrations across 100 or 1000 years.

In the case of negative CO_2 emissions after 3000, it was left to the natural carbon sinks to absorb excess CO_2, so that atmospheric CO_2 concentrations declined slowly, and climate change was largely irreversible on centennial to millennial timescales. In the cases of ramping down CO_2 levels to pre-industrial concentrations between 100 and 1000 years, surface air temperature and sea level change exhibited a substantial timelag relative to atmospheric CO_2 because of the large thermal inertia of the ocean. Even 900 years after CO_2 was restored to pre-industrial levels, surface air temperature and sea level were considerably higher than under pre-industrial conditions. When atmospheric CO_2 was slowly returned to pre-industrial levels (taking 1000 years), surface air temperature decreased more slowly, and sea level continued to rise for several centuries before starting to fall. The decline of CO_2 to pre-industrial levels, taking between 100 and 1000 years, required large negative emissions (i.e. net removal of CO_2 from the atmosphere).

This work suggests that the climate system has little resilience, and that it is very difficult to return to pre-industrial levels from a given level of warming on timescales appropriate to human activities, even after complete elimination of emissions. The modelling suggested that significant negative emissions have the potential to reverse global warming, but whether CO_2 capture technology is feasible at the necessary scale is debatable.

The ability of the oceans to absorb CO_2 and heat, and thus limit the rate and immediate extent of changes in climate, can be seen as the climate system displaying resilience to the changes in the composition of the atmosphere. In recent decades, the oceans have taken up approximately 25 per cent of the annual anthropogenic CO_2 emissions to the atmosphere from major sources (Le Quéré et al. 2009). However, the capacity of the oceans to absorb CO_2 appears to be limited, because the continued absorption of CO_2 results in the oceans gradually becoming more acidic (Caldeira & Wickett 2003), with a reduction in the ocean's carbonate mineral saturation. Laboratory studies indicate that a further decrease in seawater pH of 0.2–0.3 pH units (becoming more acidic) would inhibit or slow calcification in many marine organisms, such as corals, foraminifera and some calcareous plankton, thus potentially affecting the entire marine food chain (Zeebe & Zachos 2013).

Evidence of past climate resilience may be gleaned from the climate palaeorecord. Zeebe et al. (2016) have determined that the rate of carbon released to the atmosphere during the Palaeocene–Eocene Thermal Maximum era (PETM; approximately 56 million years ago, which is considered to be the geological period with the highest carbon release rates of the past 66 million years) was 0.6–1.1 billion tonnes (petagrams; Pg) of carbon per year (Pg C/y), which is 10 times lower than the current rate (10 Pg C/y). The PETM was marked by a rapid onset of 6 °C global warming, followed by a gradual recovery across the next 150,000 years (Zachos et al. 2001). The onset was accompanied by intense dissolution of carbonate sediments throughout the deep sea and acidification of surface waters (Zachos et al. 2005), resulting in changes to biodiversity and abundancy in communities of marine calcifiers (e.g. Tremolada & Bralower 2004). Although many species ultimately survived, the community perturbations persisted for tens of thousands of years, recovering only as carbon levels abated and the planet cooled. Zeebe and Zachos (2013) suggest that the present and future rate of climate change and ocean acidification are faster than any species can adapt to, and could lead to widespread future extinctions in marine and terrestrial environments that will exceed those during the PETM. The fossil record indicates that recovery of biotic diversity after mass extinctions generally takes several million years.

Resilience of our environment and society

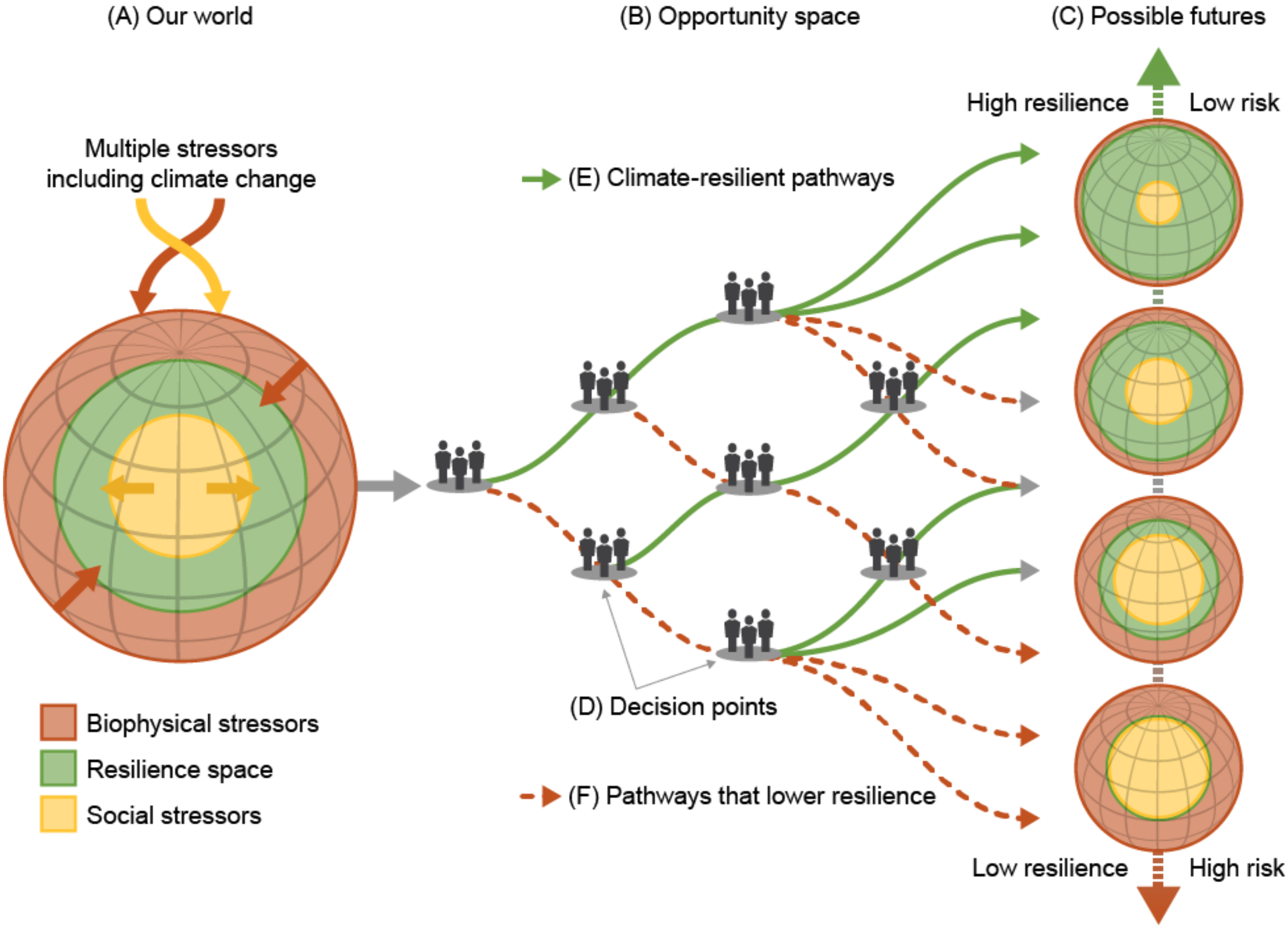
The resilience of a society is dependent on the sensitivity of the society to change and its capacity to adapt to change.

Field et al. (2014a) view adaptation as a means to build resilience and to adjust to climate change impact using the concept of climate-resilient pathways. These pathways combine adaptation and mitigation to reduce climate change and its impacts in sustainable development trajectories. Figure ATM27 demonstrates the concept of climate-resilient pathways. The resilience of 'our world' is influenced by biophysical and social stressors such as climate change, climate variability, land-use change, degradation of ecosystems, poverty and inequality, and cultural factors. Decision points and pathways in the 'opportunity space' lead to a range of 'possible futures' with differing levels of resilience and risk. Within the opportunity space, climate-resilient pathways result in a more resilient world through adaptive learning, increasing scientific knowledge, effective adaptation and mitigation measures, and other choices that reduce risks. Climate-resilient pathways may involve significant transformations in political, economic and socio-technical systems. These transformations may be reactive, forced or induced by random factors, or deliberately created through social and political processes. Pathways that lower resilience can involve insufficient mitigation, poor adaptation, and failure to learn and use knowledge.

Although both mitigation and adaptation are essential for climate risk management at all scales, the success of climate-resilient pathways will be fundamentally linked to the effectiveness of climate change mitigation (i.e. as problems become unmanageable, limits to adaptation and risks of irreversible losses increase, reducing future options for climate-resilient pathways).

Storm clouds over Cooma, New South Wales

Photo by Megan Watson



Note: (A) Our world is threatened by multiple stressors that impinge on resilience from many directions, represented here simply as biophysical and social stressors. Stressors include climate change, climate variability, land-use change, degradation of ecosystems, poverty and inequality, and cultural factors. (B) Opportunity space refers to decision points and pathways that lead to a range of (C) possible futures, with differing levels of resilience and risk. (D) Decision points result in actions or failures to act throughout the opportunity space, and together they constitute the process of managing or failing to manage risks related to climate change. (E) Climate-resilient pathways (in green) within the opportunity space lead to a more resilient world through adaptive learning, increasing scientific knowledge, effective adaptation and mitigation measures, and other choices that reduce risks. (F) Pathways that lower resilience (in orange) can involve insufficient mitigation, maladaptation, failure to learn and use knowledge, and other actions that lower resilience; they can be irreversible in terms of possible futures.
Source: Figure TS.13 from Field et al. (2014b)

Figure ATM27 Opportunity space and climate-resilient pathways

Climate change will result in vulnerabilities that are likely to be location specific. For example, high-elevation regions and arid locations are more sensitive to changes in precipitation; small island states and states with extensive coastlines are more sensitive to land inundation from sea level rise.

However, some regions may benefit from climate change. For example, warmer temperatures will reduce energy demand for winter heating and reduce winter mortality in cooler climates, including southern Australia (Bambrick et al. 2008). Forest growth in cooler regions and spring pasture growth in cooler regions would also increase, and may be beneficial for animal production (e.g. Kirschbaum et al. 2012).

In Australia, recent extreme climatic events show the significant vulnerability of some ecosystems and many human systems to current climate variability (Reisinger et al. 2014):

- High sea surface temperatures have repeatedly bleached coral reefs in north-eastern Australia since the late 1970s and more recently in Western Australia; the 2016 bleaching event affected 93 per cent of the Great Barrier Reef (Hughes et al. 2016).
- Widespread drought in south-eastern Australia (1997–2009) resulted in substantial economic losses.
- The south-eastern Australian heatwave in late January 2009 resulted in 374 more deaths in Victoria than would have been expected.
- The Victorian bushfires in early February 2009 killed 173 people and more than 1 million animals, destroyed more than 2000 homes, burned about 430,000 hectares, and cost about $4.4 billion.
- The floods in eastern Australia in early 2011 cost about $12 billion in lost revenue, mainly through lower coal and agricultural production.
- Heatwaves in 2013 (Australia's hottest year), 2014 and 2015 had substantial impacts on infrastructure, health, electricity supply, transport and agriculture.
- From November 2015 to January 2016, South Australia's Pinery bushfires (26 November), the Sydney tornado (17 December), the Great Ocean Road bushfires in Victoria (26 December) and the bushfires in Western Australia's south-west (8 January) cost $515 million in insured losses (ICA 2016).

The frequency and/or intensity of such events are projected to increase in many locations (Whetton et al. 2015). Without adaptation, changes in climate, sea level, atmospheric CO_2 and ocean acidity are projected to have substantial impacts on water resources, coasts, infrastructure, health, agriculture and biodiversity (Reisinger et al. 2014). Freshwater resources are projected to decline in far south-western and far south-eastern mainland Australia. Rising sea levels and increasing heavy rainfall are projected to increase erosion and inundation, with consequent damage to many low-lying ecosystems, infrastructure and housing. Increasing heatwaves will increase risks to human health; rainfall changes and rising temperatures will shift agricultural production zones; and many native species will suffer from range contractions (some may face local or even global extinction) (Reisinger et al. 2014).

People who are socially, economically, culturally, politically, institutionally or otherwise disadvantaged are most sensitive to climate change. Sensitivity is usually the result of cross-cutting social processes, such as discrimination on the basis of gender, class, ethnicity, age and disability, and result in inequalities in socio-economic status and income, as well as in exposure to risk. Climate-related hazards affect poor people's lives directly by affecting livelihoods, reducing crop yields or destroying homes, and indirectly by increasing food prices and food insecurity. Climate change impacts are expected to exacerbate poverty in most developing countries and create new poverty alcoves in countries (both developed and developing) with increasing inequality.

It is important that vulnerabilities in social resilience are reflected in national and international policies aimed at adapting to climate change. For example, social protection measures, insurance programs and disaster risk management may enhance long-term livelihood resilience among poor and marginalised people, if policies address poverty and multidimensional inequalities (Field et al. 2014a). These communities are likely to be the greatest beneficiaries of action towards a low-carbon future (Harrington et al. 2016).

Within Australia, several reports have suggested that Indigenous communities, particularly those living in remote interior or low-lying coastal areas, may be particularly vulnerable to climate change impacts (Hennessy et al. 2007, Altman & Jordan 2008, Green et al. 2009). In urban and regional areas, where 78 per cent of the Indigenous population lives (ABS 2013), assessments have not specifically addressed risks to Indigenous people (Reisinger et al. 2014). However, socio-economic disadvantage and poor health indicate that Indigenous Australians are disproportionately vulnerable to climate change (McMichael et al. 2009, SCRGSP 2014). Whether in remote or urban areas, the natural environment may also form an important part of Indigenous peoples' culture and spirituality (Hennessy et al. 2007), and changes to the environment will therefore have an effect.

Green et al. (2009) summarise the regional projected impacts of climate change to which Indigenous communities may be particularly vulnerable. Projections by Whetton et al. (2015) indicate that, in northern Australia, substantial changes to wet-season and annual rainfall are possible across the century, but low confidence exists about the direction of future rainfall change (i.e. whether rainfall will increase or decrease). Sea surface temperatures near tropical northern Australia are projected to increase, and sea level rise in the tropical north of Australia will have the most significant impact in the short to medium term when combined with extreme events such as king tides and storm surges. Some studies indicate an increase in the proportion of tropical cyclones in the more intense categories, but a possible decrease in the total number. These impacts could result in more heat stress, stress on water reserves, and storm disturbance and coastal inundations. In particular, sea level changes may have severe consequences for those in Torres Strait (Hennessy et al. 2007).

Climate change is expected to affect the distribution of species in Australia (Steffen et al. 2009), which may affect Indigenous people who are highly reliant on natural resources for their livelihoods. For example, 80 per cent of adults living in Indigenous communities fish or hunt for livelihood (Altman & Jordan 2008). Income from fishing is also of economic significance in more settled regions such as coastal New South Wales (Gray et al. 2005). Indigenous people also rely on natural resources for their cash income, as in the case of commercial farming of native foods, or arts and craft industries that rely on native plants as materials (e.g. Altman & Whitehead 2003).

Adaptation efforts may also disadvantage Indigenous communities. For example, forced or involuntary migration to urban centres from areas rendered uninhabitable by climate change (including rural and remote regions, and low-lying islands or coastal zones) might cause major economic, social, cultural and even psychological damage. Traditional land that Indigenous and traditional peoples inhabit represents the fundamental core of their cultures (Macchi et al. 2008). Some Indigenous groups have occupied their traditional lands without interruption since precolonial times. In other situations, Indigenous groups have fought hard for native title rights and the associated right to live on their traditional lands.

Adaptation and mitigation to climate change can, however, also offer opportunities for Indigenous communities. Indigenous engagement with environmental management can improve health and may increase adaptive capacity (Burgess et al. 2009, Hunt et al. 2009). Extensive land ownership in northern and inland Australia, and land management traditions mean that Indigenous people are well situated to provide GHG abatement and carbon sequestration services, which may also support their livelihood aspirations. For example, the West Arnhem Land Fire Abatement project is a commercial agreement based on customary knowledge of fire management that produces a tradeable carbon offset (Altman et al. 2007, Heckbert et al. 2012; Box ATM7) Other potential opportunities include feral animal management (to reduce methane emissions), carbon sequestration (tree planting) and geo-sequestration (Altman & Jordan 2008).

Box ATM7 West Arnhem Land Fire Abatement project

Annually, 20–80 million hectares, or 3–10 per cent of Australia's land area, is affected by bushfires; 85–98 per cent of these fires occur in the topical savanna woodlands and rangelands. Methane and nitrous oxide produced from the combustion contribute 2–3 per cent of Australia's total greenhouse gas emissions.

The majority of these fires occur during the late dry season, which is a relatively recent phenomenon. Before the depopulation of these lands in the past century, Indigenous people practised a complex pattern of fire management to encourage new growth, to help with hunting, to protect important places and resources, and for ceremonial purposes.

Fires ignited in the late dry season tend to persist for days or weeks; hence, late-season fires are large in area compared with early-season fires, which are more likely to self-extinguish after burning a smaller area. Late-season fires are also more intense and complete, and tend to burn more of the available fuel.

Cook (1994) identified that a shift from late to early dry-season burning would reduce annual greenhouse gas emissions because carbon stored in dead fuels increases, and because carbon and nitrogen otherwise emitted as climatically active methane and nitrous oxide are instead recycled to the atmosphere as greenhouse-neutral carbon dioxide and nitrogen through biological processes. To test the hypothesis, the North Australian Indigenous Land and Sea Management Alliance Ltd (NAILSMA) established the West Arnhem Land Fire Abatement (WALFA) project to engage Indigenous landowners to reintroduce traditional fire management using modern technology. The pilot project demonstrated that fire management can reduce the area burned by 30 per cent and reduce emissions by around 0.6 megatonnes of carbon dioxide equivalent per year (Russell-Smith et al. 2013).

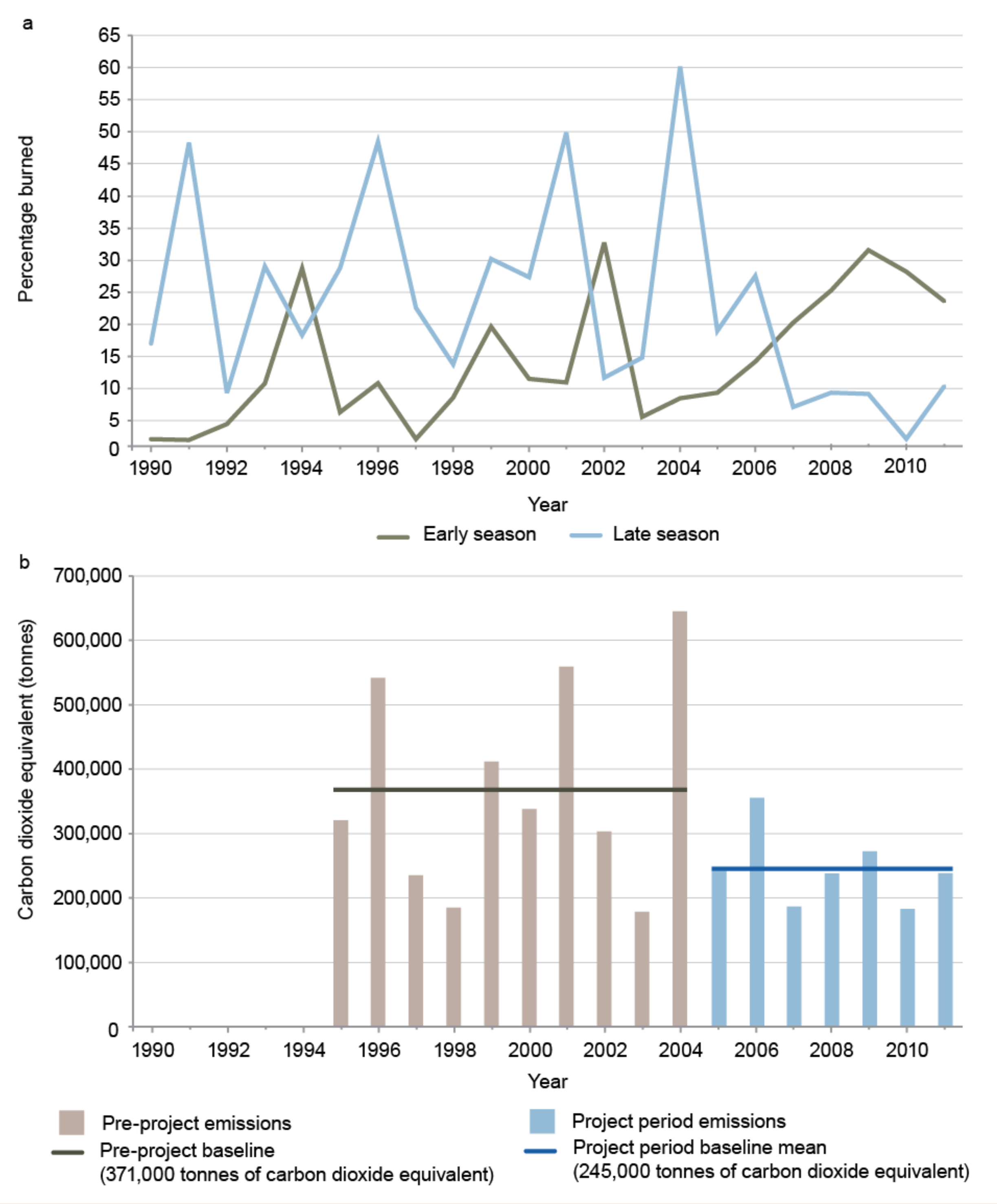
Indigenous fire manager carrying out prescribed burning

Photo by Romeo Lane

Consequently, an abatement methodology was developed under the Carbon Farming Initiative, and translated to the Emissions Reduction Fund for regions of the savanna woodlands that have an average annual rainfall of more than 1000 millimetres (Figure ATM28). Currently, 15 million hectares of this region is now under active management. The emissions abatement methodology has been extended to include the 600–1000 millimetre rainfall region, and a new methodology to account for carbon storage in dead fuels is close to finalisation.

Source: NAILSMA

Box ATM7 (continued)



Source: Adapted from Russell-Smith et al. (2013)

Figure ATM28 Application of Australia's savanna burning emissions accounting methodology to the West Arnhem Land Fire Abatement project (WALFA) area: (a) seasonality of burning in the WALFA area, 1990–2011, derived principally from Landsat imagery; (b) resultant calculated savanna burning emissions in pre-project baseline period (1995–2004) and project period (2005–11), where horizontal lines represent mean emissions for respective periods

Risks
to Australia's climate

At a glance

An understanding of the risks associated with Australia's climate will lead to improved action plans to adapt to the changes predicted to occur. Our climate is a dynamic system; therefore, the risks need to be re-evaluated frequently.

Recent climate change projections for Australia from the Intergovernmental Panel on Climate Change, CSIRO and the Bureau of Meteorology have modelled how Australia's climate is likely to evolve during the next century.

In the past century, Australia's climate has warmed by 1 °C. Mean temperatures and extreme temperatures are projected to increase, with more hot days and fewer cold days. Australia is forecast to experience increased heatwaves, leading to increased wildfire incidence and health problems (heat stress); longer droughts, extending further geographically than they have done in the past; flooding from more intense storm activity; sea level rise, leading to coastal damage; and loss of ecosystems.

Average rainfall in southern Australia is projected to decrease, with a likely increase in drought frequency and severity. Extreme daily rainfall events are projected to increase in both frequency and severity.

The sea levels around Australia are projected to rise further, with a subsequent increase in the frequency of extreme sea level events.

The IPCC updates its assessment of the global climate system every 6 years, based on global monitoring, new research, improved modelling and expert knowledge. CSIRO and the Bureau of Meteorology complement the IPCC assessment reports with a more focused study of Australia's climate in their climate projections products. The following section summarises the information from the Australasia chapter of AR5 (Reisinger et al. 2014), the Australian climate projections (Whetton et al. 2015), and the National Climate Resilience and Adaptation Strategy (Australian Government 2015b).

During the past century, Australia's climate has warmed by 1 °C, and warming is projected to continue through the 21st century ('virtually certain'), along with other changes in climate (Reisinger et al. 2014). The Paris Agreement from the 2015 Conference of the Parties (COP21) includes a commitment to limit warming globally to less than 2 °C, but achieving this will be a significant challenge. Carbon dioxide has a long lifetime in the atmosphere and can influence the climate system for thousands of years after it is emitted (see Resilience of Australia's climate) (Solomon et al. 2009).

A warming climate will lead to more frequent heatwaves, which can be responsible for deaths in vulnerable populations such as the sick and elderly. In Victoria, 374 more deaths were recorded during the heatwave of January 2009 than would normally be expected at that time of year (DHS 2009). Heat stress and dehydration also affect the wellbeing of the general population. Conditions for the spread of many diseases will become more favourable, such as the increased geographical spread of pathogen-carrying mosquitoes.

A warming and drying climate is projected to lead to an increase in extreme fire-danger days in southern and eastern Australia. Intense bushfires can destroy housing and infrastructure in affected areas, and may threaten human life.

Australia is likely to experience more frequent intense rainfall events, causing flood damage to our housing and infrastructure ('medium to high confidence'; Reisinger et al. 2014). It is estimated that the floods of 2010–11 in Queensland cost more than $5 billion in damage and killed 33 people (Holmes 2012). The occurrence of cyclone events varies greatly from year to year and decade to decade. In the long term, there may be a decrease in the overall number of cyclones, but an increase in the proportion of more intense storm events in tropical regions, which may also occur further south of 25° latitude.

Some regions have shown reduced rainfall and increased drought in recent decades. In the Perth region, flows into dams decreased from 338 gigalitres per year in 1911–74 to just 65.8 gigalitres per year in 2006–13 (Water Corporation WA 2009).

Droughts are projected to increase in length and geographical area, leading to increased water shortages in southern Australia. This will largely be driven by a projected reduction in rainfall in winter and spring. Droughts affect agricultural zones, particularly in the Murray–Darling Basin, and far south-eastern and south-western Australia, limiting our ability to grow food and provide pasture for farm animals. Droughts also reduce the water in rivers and streams, required as drinking water for an increasing population and to sustain a range of ecological systems. Our forested regions face an increase in tree mortality and reduced productivity.

Because the surrounding oceans have such a large impact on the variability of the Australian climate, the likely future changes in these systems are an important area of research. Warming of the Indian Ocean because of global warming (Lee et al. 2015) may have played a role in the moderation of the El Niño drying in some parts of Australia in 2015. Furthermore, the nature of ENSO events themselves may change as the climate system warms (e.g. Power et al. 2013, Cai et al. 2015, Chung & Power 2016), with possible consequences for Australia.

Increased temperatures and acidification of the oceans are causing inherent risks to our ecosystems. For example, the impact of bleaching on coral systems is evident in the Great Barrier Reef. The seas surrounding Australia rose by 20 centimetres between 1901 and 2010. Because most Australians inhabit coastal areas, these regions have a high economic and social value. Low-lying regions such as Port Phillip Bay (Melbourne) are particularly vulnerable to sea level rise and storm surge events in the next century. Coastal land, our beaches and amenities will be lost.

The severity of the impacts of weather and climate events depends strongly on the level of vulnerability and exposure to these events. Vulnerability and exposure are dynamic, varying across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance and environmental factors. High vulnerability and exposure are generally the outcome of skewed development processes, such as those associated with environmental mismanagement, demographic changes, rapid and unplanned urbanisation in hazardous areas, failed governance, and a scarcity of livelihood options for the poor (Cardona et al. 2012).

Brighton Beach, Victoria
Photo by Phil McFadden

Assessment summary 3

Risks to climate

	Catastrophic	Major	Moderate	Minor	Insignificant
Almost certain		Australia's average temperature will increase, with more hot extremes and fewer cold. This will result in increased frequency of heatwaves Sea levels will continue to rise throughout the 21st century and beyond Oceans around Australia will warm and become more acidic			
Likely		In southern Australia, winter and spring rainfall will decrease over the whole century, although increases are projected for Tasmania in winter The time in drought will increase for southern Australia, with a greater frequency of severe droughts A projected increase in evaporation rates will contribute to a reduction in soil moisture in southern Australia Southern and eastern Australia are projected to experience harsher fire weather There will be a decrease in snowfall and an increase in snowmelt, and thus reduced snow cover Extreme rainfall events that lead to flooding are likely to become more intense The number of tropical cyclones is projected to decrease, but with a greater proportion of intense cyclones. Higher sea levels and rainfall intensity will affect their impact			
Possible					
Unlikely	One or more climate change tipping points will be passed, triggering abrupt, nonlinear and irreversible changes in the climate system				
Rare					

Outlook

for Australia’s climate

At a glance

The outlook for Australia’s climate depends on the effectiveness of international and national efforts to reduce greenhouse gas emissions. Without mitigation, surface temperature increases of 3.7–4.8 °C above 1850–1900 temperatures are projected. To remain below 2 °C warming above pre-industrial levels, a reduction in global anthropogenic greenhouse gas emissions of 40–70 per cent by 2050 compared with 2010, and near zero emissions or below in 2100 are required. Serious mitigation strategies are required to achieve this.

Mitigation efforts will minimise the extent of future climate change and prevent catastrophic climate change tipping points, but will not return the climate system to its pre-industrial state. Despite international and domestic mitigation efforts, temperatures will remain high for many centuries, even after a complete cessation of net anthropogenic greenhouse gas emissions. Hence, adaptation will be an important component of the way society handles climate change.

> *Effective emissions reductions efforts and climate change adaptation together will bring important benefits: social, environmental and economic impacts will be lower; new opportunities can be fully exploited; and fresh thinking about climate risks will stimulate innovation in other fields.* (Australian Government 2015b)

The outlook for Australia’s climate is influenced by the global climate outlook. Without mitigation to reduce GHG emissions, modelling suggests that growth in population and economic activities alone will see the median surface temperature increase by 3.7–4.8 °C above 1850–1900 temperatures (Edenhofer et al. 2014b). However, under the Paris Agreement, 195 nations have agreed to hold the increase in the global average temperature to below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C.

For it to be likely that warming during the 21st century will remain below 2 °C, CO_2-e concentrations need to be stabilised at less than about 450 parts per million (ppm) by 2100. This would require a reduction in global anthropogenic GHG emissions of 40–70 per cent by 2050 compared with 2010, and near zero emissions or below in 2100. Concentrations of about 500 ppm CO_2-e by 2100 are still likely to limit temperature change to less than 2 °C and are likely to result in temperature rise of less than 3–4 °C by 2100. This scenario would require global 2050 emissions levels to drop by about 25–55 per cent from the level in 2010 (Edenhofer et al. 2014b).

Thus, the outlook for Australia’s climate depends on the effectiveness of international and national efforts to reduce GHG emissions. Mitigation and adaptation require international and domestic cooperation. International cooperation provides the overarching frameworks and drivers for mandating domestic policy and action. Internationally, the United Nations Framework Convention on Climate Change provides this, and the Paris Agreement provides the latest mechanism for the implementation of the framework. Domestically, there needs to be bipartisan agreement to act on climate change and implement policies that will reduce or mitigate emissions.

Serious mitigation strategies are required. Encouragingly, robust evidence shows that reductions in the carbon intensity of electricity generation, efficiency enhancements and behavioural changes will lead to a reduction in energy demand that does not compromise development (Edenhofer et al. 2014b).

In scenario modelling using the low-concentration pathway (e.g. 450 ppm by 2100), CO_2 emissions from the energy supply sector show a reduction greater than 90 per cent below 2010 levels by 2040 and 2070. Low-carbon electricity supply from renewable energy, nuclear energy, and CO_2 capture and storage increases to more than 80 per cent by 2050, when fossil fuel power generation is completely phased out (Edenhofer et al. 2014a). Reducing energy demand in the near future has the added benefits of helping industry avoid locking into carbon-intensive infrastructure, such as new coal-fired power plants, and reducing the risk of energy supply fluctuations.

Changes in human behaviour and lifestyle can significantly reduce emissions through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes (Edenhofer et al. 2014a). Land-use mitigation—including changes to forest management (including afforestation, sustainable management and reducing deforestation), changes in cropland management, changes in grazing land management and restoration of organic soils—are also considered to be potentially effective (Edenhofer et al. 2014a). In principle, mechanisms that set a carbon price, including cap-and-trade systems and carbon taxes, can achieve cost-effective mitigation. However, success of these mechanisms is varied, and dependent on national circumstances and policy design (Edenhofer et al. 2014a).

In Australia, mitigation activities include a broad suite of programs ranging from reducing emissions, enhancing energy efficiency, increasing renewable energy use, improving industrial processes, increasing sustainable transport use and enhancing carbon sinks (Australian Government 2015b), including sequestering carbon in the soil and undertaking large-scale landscape revegetation programs. Renewable energy targets and the development of more resilient systems of agricultural production are also part of the Australian strategy.

The extent to which temperatures will rise depends on the effectiveness of international actions to reduce emissions, as discussed above. The risk of catastrophic or abrupt climate change increases as the magnitude of the temperature rise increases (Stocker et al. 2013a). For example, global mean sea level rise will continue beyond 2100 because of thermal expansion (0.4 metres for 2081–2100 under the low-concentration pathway), whereas mass loss by ice sheets, which may be irreversible, would cause larger sea level rise (7 metres for a temperature rise greater than 4 °C) (Stocker et al. 2013a).

Mitigation efforts to reduce GHG emissions will aim to minimise the extent of future climate change and prevent catastrophic climate change tipping points. Mitigation will not return the climate system to its pre-industrial state—it is important to note that, despite international and domestic mitigation efforts, temperatures will remain high for many centuries even after a complete cessation of net anthropogenic CO_2 emissions. Adaptation will therefore be an important component of the way society handles climate change.

Ambient air quality

Introduction

Good air quality is essential for human health and the environment. Air quality is an important contributor to quality of life, and plays a role in the livability of our towns, cities and environment.

Ambient air quality is determined by the types and amounts of pollutants emitted into the atmosphere, and the processes associated with their transport, transformation, mixing, and removal from the atmosphere. Many different pollutants exist in our atmosphere, including gases (e.g. carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, and volatile organic compounds (VOCs) such as benzene and formaldehyde) and particulate matter (PM, including particulate matter less than 10 microns in size [PM_{10}] and particulate matter less than 2.5 microns in size [$PM_{2.5}$]).

These pollutants can interact in multiple ways to produce new pollutants, and there are several removal processes. Weather conditions have a significant influence on air quality. For example, calm winds can lead to the build-up of pollution levels in an urban environment. High temperatures, strong winds and dry vegetation exacerbate the fire risk in bushfire-prone areas, which can lead to very high smoke concentrations, both locally and in downwind urban areas. Temperature and sunlight have a strong influence on the chemical transformation of pollutants in the atmosphere.

In many cases, particularly in urban areas, local air quality is determined by a wide range of emissions from many sources across a region. The relationship between emissions (sources) and ambient air quality is complicated—describing the 'pathway' between the two is the task of air pollution modelling systems, which are often complex computer models.

Health impacts of air pollution

The major aim of monitoring and reducing air pollution is to reduce its adverse impacts on human health. Other aims are to prevent loss of amenity—for example, because of poor visibility or offensive odour, damage to vegetation, and corrosion of buildings and other infrastructure.

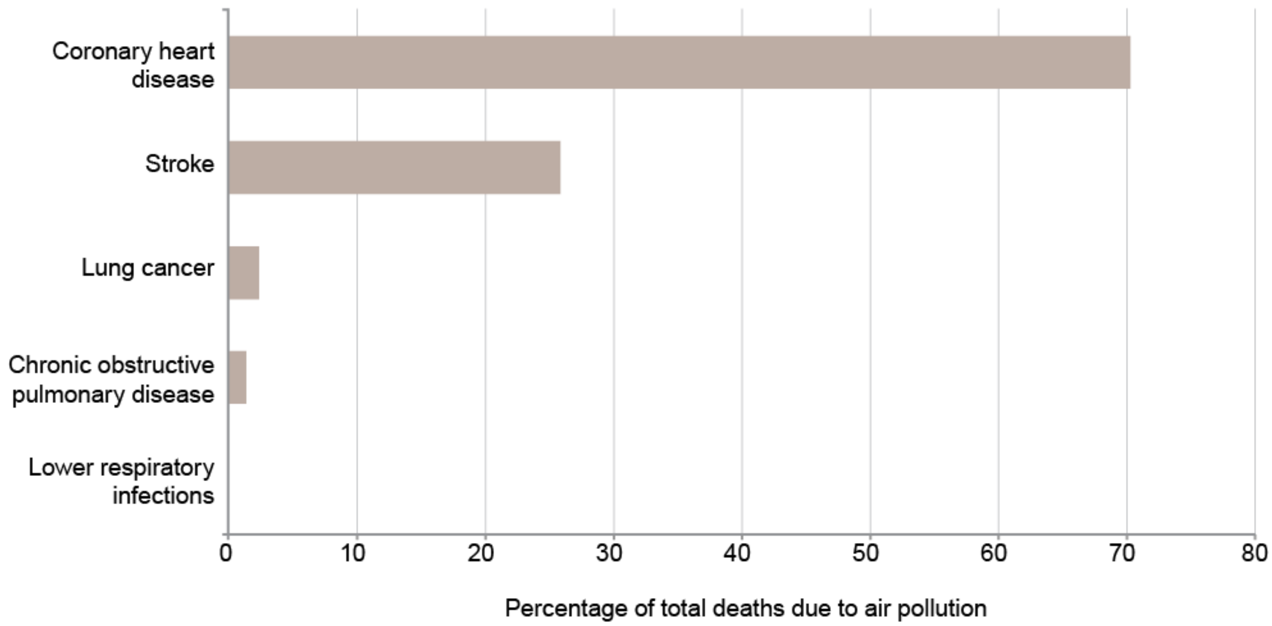
Epidemiological and controlled exposure studies have shown that the relationship between higher levels of air pollution and human health impacts is statistically significant. For example, PM can result in decreased lung function, increased respiratory symptoms, increased chronic obstructive pulmonary disease, increased cardiovascular and cardiopulmonary disease, and increased mortality (Pope & Dockery 2006). Associated with these health outcomes, research has identified a strong link between the levels of $PM_{2.5}$ and life expectancy (Pope et al. 2009). Australia does not have such widespread or hazardous levels of air pollution as some other countries, but the 2005 Australian multicity study (EPHC 2010a) established that there were significant impacts of air pollution on the morbidity and mortality of Australia's population.

Since SoE 2011, evidence for the influence of air pollutants on health has continued to mount. In 2013, the International Agency for Research on Cancer classified outdoor air pollution and one of its major components, PM, as carcinogenic to human health (Loomis et al. 2013). The Global Burden of Disease study demonstrated an increase in noncommunicable diseases in adults, such as cardiovascular disease and respiratory problems, caused partly by exposure to airborne PM (Lim et al. 2012). Another study published in 2013, comparing levels of air pollution across 14 sites in 9 countries, found links between high levels of air pollution and low birth weights. Weight at birth is a factor affecting children's health, including the risk of infection and developmental delays (Dadvand et al. 2013).

The 2013 World Health Organization *Review of evidence on health aspects of air pollution* examined newly accumulated scientific evidence on the adverse effects on health of PM, ozone and nitrogen dioxide, at levels commonly present in Europe (WHO 2013). The review supported the scientific conclusions of the World Health Organization's air quality guidelines, last updated in 2005, and indicates that effects can occur at air pollution concentrations lower than those on which the guidelines are based. It also provides a strong scientific argument for taking decisive actions to improve air quality and reduce the burden of disease associated with air pollution. In other words, the new evidence no longer supports the notion that there is a safe level for pollutant concentrations.

The Australian Institute of Health and Welfare (AIHW 2016) has estimated that about 3000 deaths (equivalent to about 28,000 years of life lost) are attributable to urban air pollution in Australia each year (Figure ATM29). The health costs from mortality alone are estimated to be in the order of $11–24 billion per year (Begg 2007, Access Economics 2008). The health risk assessment undertaken for the review of Australia's air quality standards (Golder Associates 2013) found that the most severe effects, in terms of overall health burden, were linked to long-term exposure to high levels of PM. Better control of nonroad spark-ignition engines and equipment to reduce emissions could avoid health costs by up to $1.7 billion (COAG 2015a).

Dennekamp et al. (2015) found an association between out-of-hospital cardiac arrest and $PM_{2.5}$ in Melbourne during the summer of 2006–07, when smoke from fires burning in the alpine region affected Melbourne residents. In February and March 2014, a fire in the Morwell open-cut mine in Gippsland, Victoria, blanketed Morwell and the surrounding area in smoke for about 6 weeks, prompting the Victorian Chief Health Officer to recommend the temporary evacuation of vulnerable residents from the town to avoid immediate adverse health effects. In response to community concerns about the long-term health effects of smoke exposure, the Hazelwood Health Study was commissioned, which will identify potential impacts.



Source: AIHW (2016)

Figure ATM29 Burden of disease attributable to urban air pollution

Ambient air quality: 2011–16 in context

Overall, the pressures on air quality remain very similar to those present in 2011: a growing population, greater urban density and increasing car travel, but a slowing in the growth of public transport patronage. For most of the population, air quality remains 'good' to 'very good', but there are ongoing issues in a number of locations, as well as impacts from bushfires and dust storms.

The 2014 Hazelwood mine fire was a major air pollution event that severely affected the adjacent town of Morwell for many weeks, with a complex mix of combustion pollutants and 24-hour average $PM_{2.5}$ levels exceeding 500 micrograms per cubic metre (μg/m^3) at times. Extreme PM concentrations were also recorded across much of New South Wales and southern Queensland because of the September 2009 dust storm, with maximum 24-hour PM_{10} concentrations of 1000–2000 μg/m^3.

The restructuring of operational and expert support for the National Environment Protection Council (NEPC) during the past 5 years has slowed progress on some air quality improvements foreshadowed in SoE 2011. However, the extensive work undertaken for the review of the National Environment Protection Measure (NEPM) air quality standards finally bore fruit with the tightening of the PM standards in early 2016:

- The $PM_{2.5}$ standards were upgraded from advisory to performance status.
- A new annual average PM_{10} standard of 25 μg/m^3 was added.
- The rule for allowable exceedances was tightened.

The revision also added a new requirement for a $PM_{2.5}$ population exposure metric to be reported annually from 2018. But review of standards for the other pollutants—ozone, nitrogen dioxide and sulfur dioxide—continues more than 10 years after the review was initiated in 2005.

An important new initiative on the policy front is the National Clean Air Agreement, which was released at the end of 2015. This provides a framework for all environment ministers to work together to identify and prioritise specific air quality issues, and to develop effective and efficient policy using a mix of approaches, such as standards; emissions reduction measures; partnerships; and better knowledge, education and awareness.

Compared with other aspects of the environment, comprehensive data are available to describe the state of air quality for much of the population. Most jurisdictions now provide real-time air quality data online, with the ability to download data. Work is progressing on the roll-out of a National Air Quality Data Service to be run by the Bureau of Meteorology, which will provide much better access to data for the community and a wide range of users.

Open-cut mining is a significant source of particulate matter emissions in the National Pollutant Inventory
Photo by Mark Hibberd

Pressures

affecting Australia’s air quality

At a glance

Australian ambient air quality is mostly affected by increasing human activity and climate change.

The population of Australia’s major cities continues to increase, with both increasing urban density and expanding boundaries. The corresponding increase in emissions from transport, energy and resource use, and the concentration of these emissions—for example, in traffic congestion—put ongoing pressure on air quality.

Wood smoke from domestic wood heaters remains a major pressure on winter air quality in many regions (contributing 50 per cent or more to levels of fine particulate matter), with no effective controls yet implemented because of social and political complexities.

Longstanding pressures are present from industrial, commercial, domestic, on-road and off-road emissions. Increasing focus is on the pressure from nonregulated sources, such as nonroad diesel engines and equipment (including shipping and rail transport), as well as nonroad spark-ignition engines and equipment such as gardening equipment.

Climate change is also a pressure on air quality. The increasing prevalence of extreme heatwaves has an impact on the chemical reactivity of the atmosphere, promoting the formation of photochemical smog. In addition, an increase in heatwaves increases the risk of fire, leading to a greater impact of smoke on Australia’s airsheds; and changes in rainfall could lead to reduced precipitation and drought, promoting dust events. Increased temperatures cause human discomfort, encouraging people to seek mitigation from cooling systems, which places pressure on power requirements and emissions to the atmosphere.

The pressures affecting Australia’s air quality arise from the drivers discussed in the *Drivers* report and have not changed significantly since 2011. The main pressures are increasing human population, levels of consumption of energy (including in vehicles), and extraction and use of resources. Some of these pressures are balanced by improvements in infrastructure and equipment (e.g. cleaner vehicles; cleaner energy, including renewables; cleaner industrial and commercial operations).

Dust storm near Mount Ebenezer, Northern Territory
Photo by Allan Fox

Pollution types

Pollutants occur as gases (e.g. carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, VOCs such as benzene and formaldehyde) and PM. In air pollution, PM refers to solid and liquid particles suspended in air, and the PM and air mixture is referred to as aerosol. PM with recognised human health impacts is PM_{10} and $PM_{2.5}$. Pollutants can be primary or secondary (Table ATM3). Many gaseous and particulate pollutants are emitted from combustion in vehicle engines, industrial processes and domestic wood heaters.

Primary air pollutants are emitted directly into the air from a source. They can have direct impacts or be precursors for secondary air pollutants (formed through reactions in the atmosphere), as discussed below.

PM_{10} and $PM_{2.5}$ are complex mixtures of particles with different sizes and chemical components; their formation is influenced by multiple sources and processes. Primary particles are emitted directly to the atmosphere and are generally large, so contribute most to PM_{10}. Natural sources of PM are processes that occur naturally in the Earth system (e.g. bubbles bursting on the sea surface to produce sea salt particles, erosion

Table ATM3 Major sources of air pollutants and particulate matter

Type of pollutant	Pollutant	Major sources
Primary pollutants	Carbon monoxide	• Combustion, including biomass (vegetation) burning in domestic wood heaters, prescribed burns and bushfires, motor vehicles and metal manufacturing
	Lead	• Road dust, metal manufacturing and metal ore mining
	Nitrogen dioxide (NO_2) and nitric oxide (NO), generalised as NO_x	• Combination of nitrogen and oxygen during high-temperature combustion of fossil fuels • Motor vehicle exhaust (responsible for about 80% of urban NO_2) • Electricity generation in fossil-fuelled power stations, petrol and metal refining, food processing and other manufacturing industries
	Sulfur dioxide	• Electricity generation in coal-fired power stations; metal smelting of sulfurous ores, including lead, copper, zinc, aluminium and iron
	PM_{10}	• In non-urban areas: biomass (vegetation) burning in domestic wood heaters; prescribed burns and bushfires; windblown dust from agriculture, mining, other land uses and the natural environment; road dust • In urban areas: motor vehicles, domestic wood heaters (in winter), construction activities and secondary particles
	$PM_{2.5}$	• Contains both primary and secondary pollutants • Combustion sources, secondary nitrates and sulfates, secondary organic aerosol and natural-origin dust
Secondary pollutants	Ozone	• Atmospheric photochemical reactions of primary pollutants, NO_x and hydrocarbons (volatile organic carbons) from motor vehicles and industry • Naturally occurring background ozone

$PM_{2.5}$, PM_{10} = particulate matter with an aerodynamic diameter smaller than 2.5 or 10 microns, respectively that generates dust, naturally lit bushfires that generate smoke). Anthropogenic sources include:

- dust associated with agricultural, mining and urban developments
- traffic-related suspension of road particles
- smoke from bushfires, prescribed burning and household wood heaters
- emissions from vehicle exhaust, industrial processing and commercial activities
- spray drift from aerial application of agricultural and horticultural chemicals.

Secondary pollutants (such as ozone) are not directly emitted by a source, but result from the chemical reactions of primary pollutants (such as oxides of nitrogen and VOCs), often in the presence of sunlight (photochemical reactions)—they therefore predominate during the warmer months. Secondary particles are formed by chemical reactions in the atmosphere that convert gases to particles; these are also often referred to as secondary aerosols. These conversions lead to the production of large numbers of very small particles (nucleation) and the growth in size of existing particles (condensation).

It is worth noting that every location has a certain level of naturally occurring air pollution, which defines the background air quality. The sources can be distant sources, because pollutant gases and fine particles can travel hundreds or thousands of kilometres. They can also be local, such as the emissions of VOCs from eucalypts, which are a precursor to the formation of secondary particles that scatter light and cause the Blue Mountains to be 'blue'. Control strategies can do very little to abate background sources of natural air pollution.

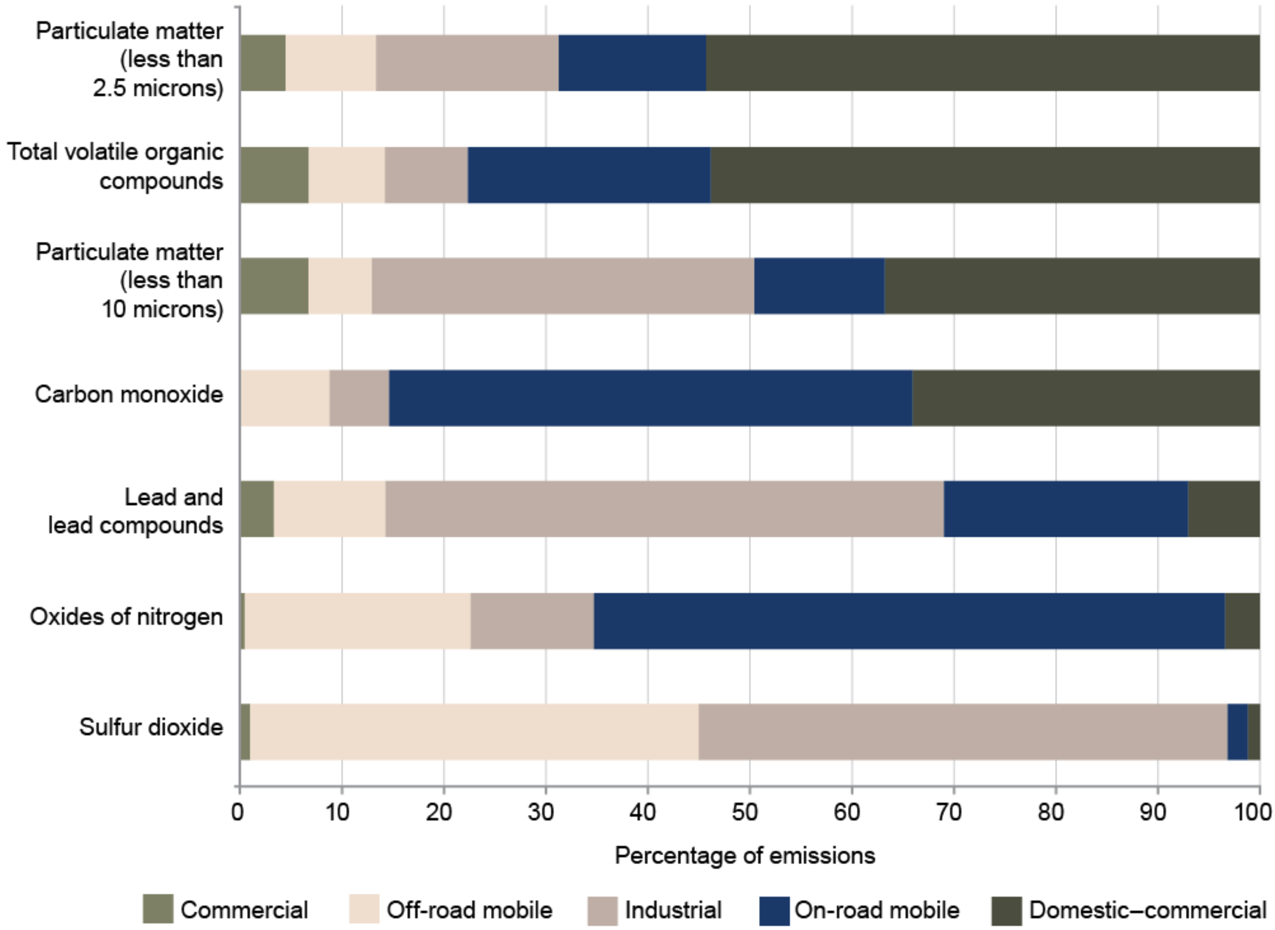
Pollen and fungal spores are other airborne pollutants that can have adverse health impacts. When inhaled, proteins and glycoproteins associated with pollens can interact with the immune systems of sensitive individuals to produce an allergic response in the form of hayfever or allergic asthma (e.g. Simpson et al. 2005).

Pollution sources

Pollution sources are often characterised as anthropogenic (i.e. human-made), biogenic (i.e. natural and living) or geogenic (i.e. natural and nonliving). For air quality, most of the concern is about anthropogenic emissions, because natural sources are generally not able to be controlled. However, the distinction is not always clear-cut—for example, management of woodland, including the use of prescribed burns (anthropogenic), could reduce the frequency or intensity of smoke emissions from bushfires (natural).

The most important anthropogenic sources of air pollution are motor vehicles, industry, and some commercial and domestic activities, especially domestic wood heaters. Other contributors to poor air quality include soil dust from the landscape, spray from waves breaking in the ocean, emissions from plants, and smoke from bushfires and prescribed burns. The contribution from pollution sources varies between regions (spatially) and time (e.g. summer–winter and day–night), depending on which sources are emitting in that area and at that time. The pattern of concentrations in Box ATM8 reflects the location of the sources but, as discussed under Introduction, the relationship between emissions and ambient air quality is often not so straightforward.

Figure ATM30 shows the proportion of anthropogenic-source categories in the Sydney region that contribute to total emissions of pollutants from the 2008 inventory (which was published in 2012). Detailed emissions inventories are available for Melbourne and south-east Queensland, but these have not been updated since SoE 2011. The commercial sources include the range of manufacturing and food processing that is typically found in industrial zones within, or on the edge of, urban areas. The domestic–commercial sources are principally domestic, but include aerosol and solvent emissions from commercial operations. They are dominated by emissions from domestic wood heaters and lawn mowing.



Source: 2008 calendar year air emissions inventory for the greater metropolitan region in NSW, NSW Environmental Protection Agency

Figure ATM30 Proportion of annual anthropogenic emissions by source type in the Sydney region

VOCs come from a wide range of sources:

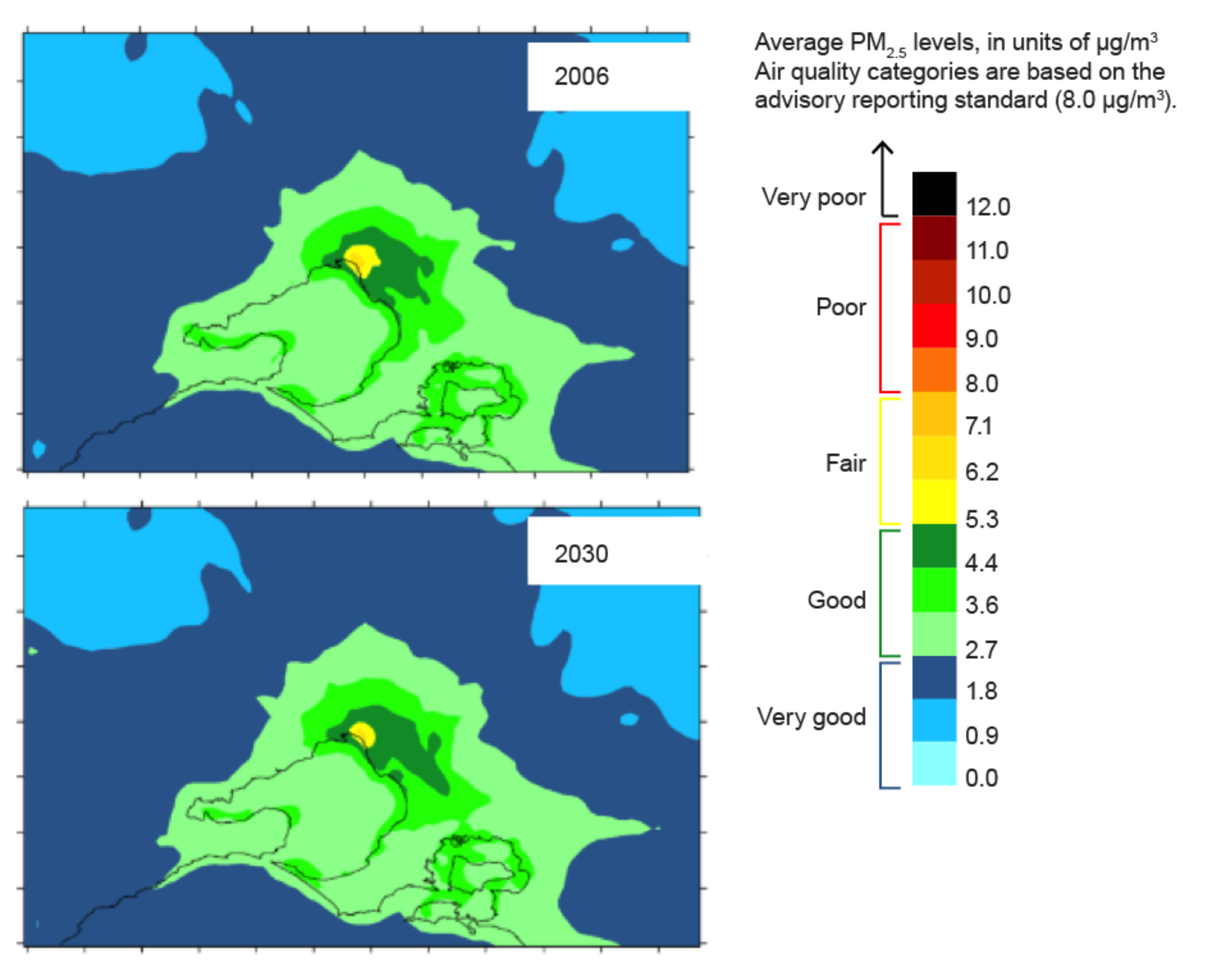
- those that emit solvents, including as aerosols, such as from spray painters and dry-cleaners
- industrial sources, including major industries such as power stations, mining and chemical manufacturing
- off-road mobile sources, including locomotives, shipping and boating, off-road vehicles and equipment, and aircraft
- on-road mobile sources, including both tailpipe and non-tailpipe sources (e.g. brake dust) from vehicles registered for on-road use.

Notable changes in the inventory since SoE 2011, when the 2003 inventory was available, include less total sulfur dioxide from industry, and a greater fraction of sulfur dioxide emitted from off-road mobile sources such as shipping. The proportion of on-road mobile sources of carbon monoxide has decreased in the 2008 inventory, and domestic commercial activities have increased. The proportion of lead emissions from industrial processes has increased in the 2008 inventory.

Box ATM8 Future air quality in Victoria project

Work from CSIRO and the Victorian Environment Protection Authority forecasted what air quality in Victoria might be like in the year 2030 (EPA Vic 2013). The project investigated changes between the base year—2006—and 2030, including predicting how the Victorian emissions might change because of population increases, and what impacts climate change might have on day-to-day air quality through changes in weather conditions.

New technology is likely to reduce emissions from motor vehicles, even though the use of transport will increase because of an increasing population. The projected Melbourne–Geelong population increase of 45 per cent will place a higher demand on power generation, and increase the emissions from domestic and small business sectors. The projected increase in population will mean that more people are exposed to air pollution, especially the increased proportion of people aged 65 years and over. Increased occurrences of air pollution–related health effects, such as heart and lung disease, are expected.



$PM_{2.5}$ = particulate matter less than 2.5 microns

Figure ATM31 Predicted 10-year average $PM_{2.5}$ levels, 2006 and 2030

Box ATM8 (continued)

Modelled concentrations of pollutants were compared with current air quality standards. Concentrations of nitrogen dioxide; sulfur dioxide; carbon monoxide; and air toxics such as formaldehyde, benzene, toluene and xylene are expected to decrease in the Melbourne–Geelong area by 2030. Levels of particulate matter less than 2.5 microns will continue to be concentrated in the central business district and inner suburbs, which have the highest vehicle and population density (Figure ATM31). Secondary pollutants such as ozone also remain a concern in 2030.

Climate change had only a small impact on 2030 urban air quality in the model, but the impact is expected to be greater beyond 2030. The frequency of droughts and temperature-driven smog events is expected to increase beyond 2030 if emissions are not reduced. Increased droughts will increase dust events and, combined with the increase in temperature, increase bushfire events.

The results from this study are being used to inform future air quality management in Victoria, and to support the National Clean Air Agreement.

Source: EPA Vic (2013)

Increasing population

Globally, just over 50 per cent of the world's population lives in cities; in Australia, it is 90 per cent. In addition, most of the Australian population lives in coastal regions on just 0.22 per cent of the land area (National Sustainability Council 2013). Australia's population reached 24 million on 16 February 2016. It is expected to double in the next 50 years, with the percentage of the population living in capital cities increasing from 66 per cent in 2011–12 to 74 per cent in 2061. Most capital cities have targets to continue increasing urban population density, with at least half the population growth to be accommodated by urban infill (see the *Built environment* report). The other half of the population growth is expected to cause the spread of city boundaries, especially in Melbourne and Sydney. This urban spread is increasing the spatial extent of anthropogenic emissions, to occupy a larger portion of the airshed (a region where topography and meteorology limit the movement of air pollutants away from the area). The increasing population is most likely to generate increased emissions, both primary pollutants and precursors that can lead to elevated ozone concentrations. Thus, increases in both population and population density can increase the pressure on ambient air quality. Adverse health outcomes because of increased exposure to air pollutants may be compounded by the greater vulnerability of sensitive populations arising from an ageing demographic.

Industry

Traditional major industry is in decline in Australia, and this has produced a corresponding decrease in many emissions to air. For example, in the 5 years to 2014–15, the National Pollutant Inventory recorded decreases in total industry emissions of sulfur dioxide, carbon monoxide and ammonia of 10–15 per cent. On the other hand, in the same period, total PM_{10} emissions increased by 75 per cent and $PM_{2.5}$ by 9 per cent, all because of the increase in mining activity. Mining is not located in or near major metropolitan areas, but is sometimes close to, or encroaches on, rural towns and residences, where it can be a significant pressure on air quality. Pressure also arises from the processing and transport of the mine output to port. An additional pressure is blast fume from mine blasting, which is a yellow–orange colour because of the high concentrations of nitrogen dioxide, and can be blown beyond the mine fence line. Blast fume is easily identifiable by its colour, pungent odour and taste, and it can irritate the eyes and throat. Box ATM9 describes research into emissions from coal-seam gas extraction activities.

Expansion of the urban fringe into farmland brings suburbs closer to farming industry, and the dust, odour and noise of intensive farming can be a pressure on air quality for the incoming residents. More generally, dust and odour are the main causes of air quality complaints to environmental authorities.

Box ATM9 Research into emissions from coal-seam gas extraction activities

The coal-seam gas industry has developed rapidly in Queensland in the past 15 years, with more than $70 billion of investment in 3 coal-seam gas to liquefied natural gas (LNG) projects. LNG exports are predicted to increase from $14.7 billion in 2012–13 to $57 billion by 2018 (Energy Quest 2014). The Surat Basin is Queensland's largest coal-seam gas production region.

The Gas Industry Social and Environmental Research Alliance (GISERA), a partnership between coal-seam gas–LNG industry partners and CSIRO, is publicly reporting independent research into the socio-economic and environmental impacts of Australia's natural gas industries. Two GISERA projects assessing the atmospheric impacts of the coal-seam gas industry are under way.

The methane seepage study in the Surat Basin project will assess the greenhouse gas impact of the coal-seam gas industry, by determining fugitive emissions of methane from gas production and processing, as well as other methane sources such as natural seeps and agriculture. Methods have been trialled to characterise methane emission rates, including mobile vehicle surveys, deployment of flux chambers, and satellite and aircraft measurements. A long-term atmospheric monitoring program is under way, which will allow detection of changes in ambient methane concentrations over time. Coupling the atmospheric monitoring with inverse modelling and meteorological measurements is expected to be able to provide methane emission flux data at the regional scale.

The ambient air quality study in the Surat Basin project will comprehensively assess the region's ambient air quality. An ambient air monitoring network is measuring a wide variety of key air quality parameters, including nitrogen oxides, ozone, carbon monoxide, total and speciated volatile organic compounds, and particulate matter. Real-time data from the air quality network will be made available to the website of the Queensland Department of Environment and Heritage Protection. The transparency of this approach will have significant benefits for communities, industry and government. A detailed chemical transport air quality model is being used to explore the impact of the coal-seam gas industry on air quality in the region. Coal-seam gas–related emissions sources such as fugitive gas, gas combustion and water treatment facilities have also been characterised as part of this study.

Both these Australia-first studies will inform future regulation and monitoring of natural gas developments around Australia.

Wells and air quality station at Hopeland, Queensland

Photo by CSIRO

Motor vehicles

Motor vehicles emit a wide range of pollutants from their tailpipes, and are a major source of nitrogen oxides (NO_x) and carbon monoxide (e.g. Figure ATM30). These are supplemented by non-tailpipe emissions such as brake, tyre and road-wear particles, which will become the dominant vehicle emissions as engine emissions standards are tightened. Total vehicle kilometres travelled increased by an average of 1.9 per cent per year from 2010 to 2014. Although distance travelled by vehicles is, to some extent, mitigated by improving emissions standards, it continues to put pressure on air quality. As at 31 October 2014, the annual vehicle kilometres travelled for all road vehicles in Australia were estimated at 244 billion kilometres. Of this, 179 billion occurred in capital city and urban areas (ABS 2014a). Furthermore, total metropolitan vehicle kilometres travelled are projected to increase by 41 per cent from 2015 to 2030 (BITRE 2015).

Average growth in urban public transport was particularly strong between 2005 and 2009, with total patronage (summed across all 8 capitals) increasing by about 4.7 per cent per year. Growth in the past few years has been lower, averaging around 1.3 per cent per year between 2009 and 2013 (BITRE 2014).

Domestic wood heaters

Emissions from domestic wood heaters—particularly smoke, but also VOCs—remain a significant pressure on ambient air quality during cooler months of the year in several parts of Australia. In particular, towns in cooler inland areas that are prone to temperature inversions can suffer exceedances of the PM standards—these locations include Launceston, Tasmania; Tuggeranong, Australian Capital Territory; and Armidale, New South Wales. Impacts are also present in major cities. For example, an investigation into particle composition at Liverpool, Sydney (Cohen 2011), identified wood

Motor vehicles remain a significant source of pollution in cities
Photo by Mark Hibberd

Domestic wood heater smoke affecting neighbours in regional Western Australia
Photo by Mark Hibberd

smoke as a major source of air pollution, making up about 40 per cent of $PM_{2.5}$ during winter but dropping to almost zero during summer.

Approximately 10 per cent of Australian dwellings (900,000) used wood as the main source of heating in 2014 (ABS 2014b), with 70 per cent of these users located outside the capital cities. The proportion of dwellings using wood as their main source of heating had been trending down in the first decade of the century from 16 per cent to 10 per cent, but has remained stable since 2011, despite concerns that increasing electricity and gas prices would lead to an upsurge in the use of domestic wood heaters.

On a winter weekend day, wood smoke from domestic wood heaters in Sydney contributes as much as 48 and 60 per cent of PM_{10} and $PM_{2.5}$ particle pollution, respectively. In colder climates, such as in Armidale, wood heaters can contribute more than 85 per cent of particle pollution in winter (AECOM 2014). In 2012 in Muswellbrook, New South Wales, wood smoke was determined to be responsible for an average 62 per cent of $PM_{2.5}$ during winter (see Box ATM11).

Commercial and other domestic sources

Emissions from commercial and domestic sources (domestic wood heaters are considered separately) exert pressure on local air quality and on airshed quality. Domestic sources, for example, can affect photochemical smog by releasing VOCs.

In recent years, much focus has been on the emissions from nonroad spark-ignition engines and equipment, such as conventional 2-stroke engines used in the gardening sector (e.g. lawn mowers, outdoor handheld equipment), the marine sector (e.g. outboard engines, personal watercraft), and other equipment such as small generators. Air pollutants emitted from these engines include nitrogen oxides, VOCs, carbon monoxide, air toxins (including benzene and polycyclic aromatic hydrocarbons) and PM. These engines put pressure on urban air quality because they are high polluters relative to their engine size and use. On an individual engine basis, even the better-performing nonroad engines emit disproportionately high levels of air pollutants compared with typical modern car engines. Nonroad spark-ignition engines and equipment are responsible for two-thirds of the nonroad emissions of VOCs in Australia (EPHC 2010b).

Prescribed burning and bushfires

Both prescribed burns and bushfires emit smoke plumes, which are visible because of the PM they contain. The smoke is the product of incomplete combustion. Fire emissions rates are affected by fire behaviour and the amount of fuel being burned. Fires can emit up to 1 per cent of the fuel load as PM to the atmosphere. Smoke particles have a life of hours to days and, because they often rise high into the atmosphere, they can travel long distances and affect people a long way from the fire. Smoke irritation includes itchy eyes, sore throat, runny nose, coughing and wheezing. The fine particles (and gases) are small enough to be breathed deep into the lungs and can cause health problems.

Australian weekly bushfire frequencies increased by 40 per cent in the 5 years to 2013, particularly during the summer months (Dutta et al. 2016). The increasing threat from bushfires has increased pressure for more prescribed burning—for example, the Royal Commission into Victoria's 2009 bushfires recommended that there be a rolling annual target to burn 5 per cent of all public land. The emissions from these fires have increased pressure on air quality both close to the areas burned and in much larger urban areas affected by the smoke. Climate change is expected to increase these pressures.

Nonregulated diesel engines, including shipping and nonroad transport

Nonroad diesel engines and equipment are used in a wide variety of applications, including rail transport, mining, construction, industrial, shipping and airport services, and can be high pollution emitters. In Australia, there are no regulations or standards in place that

XPT express passenger train climbing out of Armidale, New South Wales
Photo by Mark Hibberd

limit emissions from nonroad diesel engines, but many of the countries where these engines are sourced do have controls. Regulated emissions limits for nonroad engines have been in force in the United States and European Union since the mid-1990s. China, India, Japan and Canada also have regulated emissions limits for nonroad engines.

Nationally, nonroad diesel engines (including rail and marine transport) are estimated to emit around 18,000 tonnes of PM_{10} per year (Environ 2010, 2013; Goldsworthy 2011). This is of a similar magnitude to emissions from the on-road vehicles sector. NO_x (nitrogen dioxide [NO_2] and nitric oxide [NO]) emissions from all nonroad diesel engines are estimated to be around 190,000 tonnes per year, equal to about half the total NO_x emissions from on-road vehicles. Reducing emissions from this sector would contribute to reducing particle and ozone pollution, and associated health risks in cities and regional Australia.

Emissions from ships in port are a growing pressure on ambient air quality, both locally and within the airshed. This pressure was highlighted by the recent construction of the White Bay Cruise Terminal near residential areas, without the provision of shore power. Cruise ships burning fuel with a sulfur content of up to 3.5 per cent emit high levels of fine particles and sulfur dioxide. In 2015, New South Wales introduced regulations on fuel quality for cruise ships in Sydney Harbour, but these have not yet been adopted in other ports. In mid-2016, the regulations were determined to be inoperative because of the 2015 amendments to the Commonwealth *Protection of the Sea Act 1983*.

Climate change

Climate change may also have a significant effect on air pollution. Warming and drying of the climate are projected to lead to an increase in extreme fire-danger days in southern and eastern Australia (CSIRO & BoM 2014; see Box ATM2), which will result in an increase in smoke production. Droughts are projected to increase in length and geographical extent, leading to increased water shortages in southern Australia. This could result in an increased incidence of dust events.

Increasing temperatures (see Effects of increased greenhouse gases) are likely to increase biogenic emissions and affect the chemical reactivity of the atmosphere, which would lead to increased formation of ozone and secondary particles. In urban centres, this may manifest as increased smog formation (see Box ATM8).

Assessment summary 4
Pressures affecting ambient air quality

Component	Summary	Assessment grade (Very high impact / High impact / Low impact / Very low impact)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Urban footprint	Increasing population (with concomitant increases in emissions from vehicles, equipment, heating, etc.) and increasing urban density are placing pressure on air quality	High impact —	●	●	X
Encroachment of urban development into rural fringe	Urban sprawl is moving populations closer to existing industries, including intensive agriculture, wastewater treatment facilities and hobby farms, leading to greater exposure to air pollution (especially odours and wood smoke)	High impact —	●	●	X
Industry adjacent to regional populations (principally extractive industries such as mining and coal-seam gas)	The development or expansion of these industries in rural or near-rural settings can adversely affect air quality. Both amenity and health impacts exist	High impact —	●	●	X
Industrial point sources (metropolitan and regional cities)	Point-source pollution is mostly mitigated by regulations, but there are some legacy issues with old industries	Low impact —	●	●	◆
Motor vehicles (metropolitan centres)	Increasing vehicle traffic and greater congestion are a pressure unless counterbalanced by reduced emissions per vehicle. Non-tailpipe emissions such as tyre and brake dust are continuing to increase	High impact —	●	●	◆
Domestic wood heaters	Smoke from domestic wood heaters is a major source of air pollution in many regions during cooler months	High impact —	●	●	X

Assessment summary 4 (continued)

Component	Summary	Assessment grade (Very high impact / High impact / Low impact / Very low impact)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Commercial and other domestic sources	Most commercial emissions are regulated by local authorities. Emissions from 2-stroke engines used in the gardening and marine sectors are unregulated; these engines are high polluters relative to their size and use. They therefore put pressure on urban air quality	Low impact; Stable	Somewhat adequate	Adequate	Comparable
Prescribed burning and bushfires	Smoke from prescribed burns (and, occasionally, bushfires) is a sporadic, major source of air pollution in regional and urban areas	High impact; Stable	Adequate	Adequate	Comparable
Nonregulated diesel engines, including shipping and nonroad transport	The lack of national emissions and fuel standards for this equipment (e.g. earth-moving, commercial shipping, rail transport) means that the contribution of these sources is uncertain, and potentially significant in some locations	Low impact; Stable	Somewhat adequate	Adequate	X (Not previously assessed)
Climate change	Rising temperatures and reduced rainfall increase the pressure from windblown dust and bushfire smoke. Higher temperatures increase chemical reaction rates, leading to, for example, higher ozone levels	Low impact; Stable	Adequate	Adequate	Comparable

Recent trends

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

Grades

- **Very low impact:** Few or no impacts have been observed, and accepted predictions indicate that future impacts on values such as health and aesthetics are likely to be minor
- **Low impact:** Impacts on values such as health and aesthetics have already been observed, most often localised
- **High impact:** Significant impacts on values such as health and aesthetics have already been observed, mainly affecting more sensitive members of the community
- **Very high impact:** Currently, a very serious impact on health and aesthetics for the broader population

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

State and trends
of Australia's air quality

At a glance

Since 1998, Australia has had national ambient air quality standards (National Environment Protection Measure for Ambient Air Quality—Air NEPM), which set guideline levels for 7 key air pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter (less than 10 microns in size [PM_{10}] and 2.5 microns in size [$PM_{2.5}$]) and sulfur dioxide. Monitoring against these standards is undertaken at about 75 locations in metropolitan areas and regional towns across Australia, referred to as 'compliance sites'.

An assessment of air quality from the worst performing (i.e. poorest air quality) of these compliance sites in each jurisdiction showed that air quality is either 'good' or 'very good' in Australian urban areas.

Levels of lead and nitrogen dioxide have declined markedly in all centres.

Particulate matter has been identified as a hazard to human health. Levels of PM_{10} now rarely exceed the 24-hour NEPM designed for the protection of human health. However, these good results do not mean that we can be complacent about air quality in Australia as new challenges emerge. The standard for $PM_{2.5}$, which has previously been an advisory limit only, is frequently exceeded because of extreme events such as bushfires, smog and dust storms. $PM_{2.5}$ can be transported further and persist for longer in the atmosphere than PM_{10}. We do not fully understand all the processes that lead to $PM_{2.5}$ formation; thus, in the future when the $PM_{2.5}$ limit is mandatory, we will be challenged to adhere to this limit. The good news is that more air quality management stations will begin measuring $PM_{2.5}$ as part of their routine reporting obligations.

Levels of ozone have remained stable since the 2011 state of the environment report.

Despite the complexity of the ambient air system, there is good understanding about several of the most significant pollutants because of the need to reduce air pollution to protect human health. This is particularly true for pollutants that are regulated by national air quality standards and measures.

In this section, we assess the state and trend of the pollutants for which there are national ambient air quality standards. Carbon monoxide is not covered in this update, as there has been little change since SoE 2011. We assess VOCs, including air toxics, which are the subject of a separate air quality standard. In the assessment summaries, we focus on those pollutants that have the largest effect on human health: ozone, PM_{10} and $PM_{2.5}$.

National air quality standards

The NEPC established national ambient air quality standards in 1998 as part of the National Environment Protection Measure for Ambient Air Quality (Air NEPM). The Air NEPM sets standards for the 7 key air pollutants to which most Australians are exposed: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter (PM_{10} and $PM_{2.5}$) and sulfur dioxide (Table ATM4).

Following much review and consultation, the Air NEPM, which had been last updated in 2003, was amended on 4 February 2016 with the following changes:

- The $PM_{2.5}$ standards were upgraded to performance standards from their previous status as advisory reporting standards.
- A standard for 1-year average PM_{10} of 25 $\mu g/m^3$ was added. This complements the existing standard for 24-hour average PM_{10} of 50 $\mu g/m^3$.

Table ATM4 National Environment Protection Measure for Ambient Air Quality (Air NEPM), updated 2016

Pollutant	Averaging period	Maximum concentration	Maximum allowable exceedances (goal)
Carbon monoxide	8 hours	9.0 ppm	1 day per year
Lead	1 year	0.50 μg/m³	No exceedances
Nitrogen dioxide	1 hour	0.12 ppm	1 day per year
	1 year	0.03 ppm	No exceedances
PM_{10}	1 day	50 μg/m³	No exceedances (see note)
	1 year	25 μg/m³	
$PM_{2.5}$	1 day	25 μg/m³	20 μg/m³ (2025 goal)
	1 year	8 μg/m³	7 μg/m³ (2025 goal)
			No exceedances (see note)
Photochemical oxidants (as ozone)	1 hour	0.10 ppm	1 day per year
	4 hours	0.08 ppm	1 day per year
Sulfur dioxide	1 hour	0.20 ppm	1 day per year
	1 day	0.08 ppm	1 day per year
	1 year	0.02 ppm	No exceedances

$PM_{2.5}$ and PM_{10} = particulate matter less than 2.5 microns and 10 microns, respectively; ppm = parts per million; μg/m³ = micrograms per cubic metre
Note: Before 2016, there was an allowance of 5 exceedances per year for the PM standards. This was replaced in 2016 by an exceptional event rule. An exceptional event is a fire or dust occurrence that adversely affects air quality at a particular location; causes an exceedance of 1-day average standards in excess of normal historical fluctuations and background levels; and is directly related to bushfire, jurisdiction-authorised hazard reduction burning or continental-scale windblown dust. The handling of exceptional events in the reporting of averages is specified in the Air NEPM.

- The allowance for exceedance of the PM standards on a maximum of 5 days per year was replaced by an 'exceptional event rule'. An exceptional event is a fire or dust occurrence that adversely affects air quality at a particular location; causes an exceedance of 1-day average standards in excess of normal historical fluctuations and background levels; and is directly related to bushfire, jurisdiction-authorised hazard reduction burning or continental-scale windblown dust.
- A goal was added of reducing the 1-year and 24-hour $PM_{2.5}$ standards from 8 to 7 μg/m³ and 25 to 20 μg/m³, respectively, by 2025.
- A $PM_{2.5}$ population exposure metric was added, to be reported on annually from June 2018. Development of this metric is still in progress, but a nationally consistent approach will be used for evaluation and reporting based on agreement by participating jurisdictions.

The jurisdictions (6 states and 2 territories) monitor air quality at about 75 locations across Australia. These stations are in the major metropolitan areas and some regional centres, and are sited to measure air quality that is representative of that likely to be experienced by the general population in the region. Jurisdictions report annually on their compliance with the Air NEPM based on the data from their monitoring networks.[4] Some jurisdictions have additional monitoring networks, such as the NSW Upper Hunter Air Quality Monitoring Network (OEH 2016), but results from these stations are not included in the above compliance reports.

4 See, for example, National Environment Protection (Ambient Air Quality) Measure annual reporting.

Air quality index

In a number of states, the agency responsible for monitoring air quality reports results at each station in its network in terms of an air quality index (AQI; Box ATM10) for all or some of the pollutants covered by the Air NEPM.

The method for assessing ambient air quality in this report is described in Box ATM13.

Carbon monoxide

Carbon monoxide is not discussed in SoE 2016, because there has been little change since the 2011 report. Please refer to SoE 2011 for information on carbon monoxide.

Lead

Lead levels have declined since the early 1990s, because of the ban on lead in petrol for motor vehicles. Although isolated hotspots of lead concentrations still exist in locations where lead smelting is undertaken, some of these are also decreasing. Port Pirie, South Australia, has reduced lead emissions to the atmosphere by improving its operating procedures (Figure ATM32). Lead levels at Port Pirie have continued to decrease since 2008 and have not exceeded the 0.5 $\mu g/m^3$ NEPM standard during this time.

Box ATM10 Air quality index

An air quality index (AQI) is calculated based on the relevant Air National Environment Protection Measure (NEPM) standard, or advisory standard, for that pollutant as follows:

AQI = pollutant concentration/pollutant standard × 100

This means that, at an index value of 100, the pollutant is currently at a concentration equal to an environmental standard level. The lower the index, the better the air quality.

The AQI provides a number that is easy to compare between different pollutants, locations and time periods. Five qualitative categories are used in public reporting of air quality. The categories and the AQI ranges that they represent are listed in Table ATM5, together with a qualitative description of the associated health effects.

Each category in the AQI corresponds to a different level of air quality and associated health risk.

Table ATM5 Air quality index (AQI)

Category	AQI range	Description
Very good	0–33	Air quality is considered very good, and air pollution poses little or no risk
Good	34–66	Air quality is considered good, and air pollution poses little or no risk
Fair	67–99	Air quality is acceptable. However, there may be a health concern for very sensitive people
Poor	100–149	Air quality is unhealthy for sensitive groups. The general population is not likely to be affected in this range
Very poor	≥150	Air quality is unhealthy, and everyone may begin to experience health effects. Sensitive people may experience more serious health effects

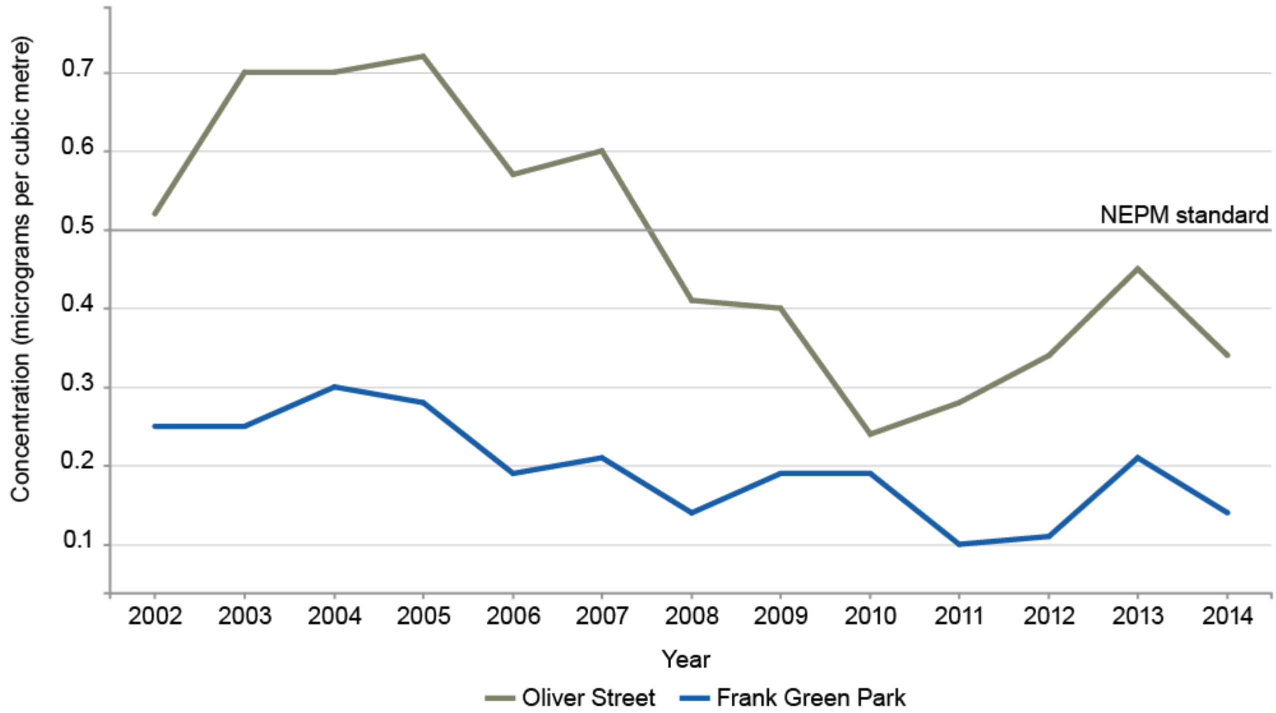


Figure ATM32 Lead levels at 2 locations in Port Pirie, South Australia, 2002–14

Nitrogen dioxide

The major source of nitrogen dioxide in Australia is burning of the fossil fuels coal, oil and gas. In cities, the predominant source is on-road vehicle emissions. The standards were met at all compliance sites in 2010–14, and have not been exceeded since the early 1990s. Peak 1-hour and annual average concentrations are equal to about one-third to one-half of the standards.

The United States National Aeronautics and Space Administration has used nitrogen dioxide levels measured by satellites to monitor air quality across the globe (Duncan 2014, NASA 2014). Its maps show the hotspots in Australia and in other countries. It reports average decreases of 20–30 per cent between 2005 and 2014 in Australian cites. Although these measurements are an average across 30 kilometre × 30 kilometre grid cells, the reported decreases are consistent with changes in annual average nitrogen dioxide concentrations reported from NEPM compliance sites, and indicate the success of tighter regulatory controls.

Although ambient concentrations are well below the standards, nitrogen dioxide concentrations up to 0.7 ppm have been measured in Sydney road tunnels (Advisory Committee on Tunnel Air Quality 2016). In the past decade, nitrogen dioxide has replaced carbon monoxide as one of the key criteria in the design of road tunnel ventilation systems to protect the health of tunnel users (the other is PM). New South Wales has recently set a limit for tunnel average concentrations of 0.5 ppm as a rolling 15-minute average (Advisory Committee on Tunnel Air Quality 2016).

Coarse particulate matter (PM_{10})

PM consists of microscopically small solid particles or liquid droplets suspended in the air. Exposure to PM has been correlated with serious public health effects, such as higher instances of asthma, decreased lung function in children, increased hospital admissions and elevated mortality rates (WHO 2013).

PM_{10} is both primary and secondary in origin, and has often exhibited a seasonal cycle dependent on bushfire smoke and episodic dust storms. Concentrations of the secondary pollutants in PM_{10} are sensitive to temperature. In winter, wood heaters are a significant source of PM_{10} in smoke for both urban and rural areas. In the 2011 assessment (which included data up to and including 2008), AQIs were good to very good for all Australian cities for PM_{10} (Figure ATM33); they have improved to very good for all cities except Darwin in the current assessment. The 50 μg/m^3 NEPM was exceeded in 2012 in Darwin, and is part of a worsening of the assessment between SoE 2011 and SoE 2016. All the 2012 exceedances in Darwin took place during the dry season and were caused by smoke drifting into the airshed from biomass burning activities nearby (NT EPA 2013).

The September 2009 dust storm affected New South Wales and Queensland, and produced extreme 24-hour PM_{10} concentrations of 1000–2000 μg/m^3 across many regions, including Sydney and Brisbane. This dust contained a significant fraction of fine PM, with 24-hour average $PM_{2.5}$ concentrations reaching 150–200 μg/m^3.

Fine particulate matter ($PM_{2.5}$)

$PM_{2.5}$ is the finer particulate fraction of PM. $PM_{2.5}$ particles are smaller, and therefore able to be transported further and persist for longer in the atmosphere than PM_{10}. In addition, the smaller the particles, the deeper they can penetrate into the respiratory system and the more hazardous they are to breathe. $PM_{2.5}$ is monitored at fewer sites than PM_{10}. This will change in the future, with the advisory NEPM standard of 25 μg/m^3 becoming a compliance standard in 2016. The AQI assessment scorecard has been used for the first time for $PM_{2.5}$ in SoE 2016.

Typical background concentrations of $PM_{2.5}$ are around 5 μg/m^3, but the concentration can increase dramatically under extreme conditions—for example, during bushfire events. Maximum concentrations of $PM_{2.5}$ have greatly exceeded the advisory standard in some areas, particularly in Sydney and Brisbane because of extreme localised events (Figure ATM34). During the 7 years from 2008 to 2014, the $PM_{2.5}$ advisory standard was met for the following number of years: Adelaide (4 years), Brisbane (5 years), Canberra (0 years), Darwin (0 years), Hobart (1 year), Melbourne (2 years), Perth (1 year) and Sydney (2 years). These data indicate that new emissions reduction strategies will be needed to meet the 2025 goal of 20 μg/m^3.

Box ATM11 describes a study to characterise $PM_{2.5}$ pollution in the upper Hunter Valley.

Figure ATM33 Average 95th percentile 24-hour average PM_{10} concentrations, 1999–2014, in (a) Melbourne, Sydney, Brisbane and Perth; and (b) Adelaide, Hobart, Darwin and Canberra

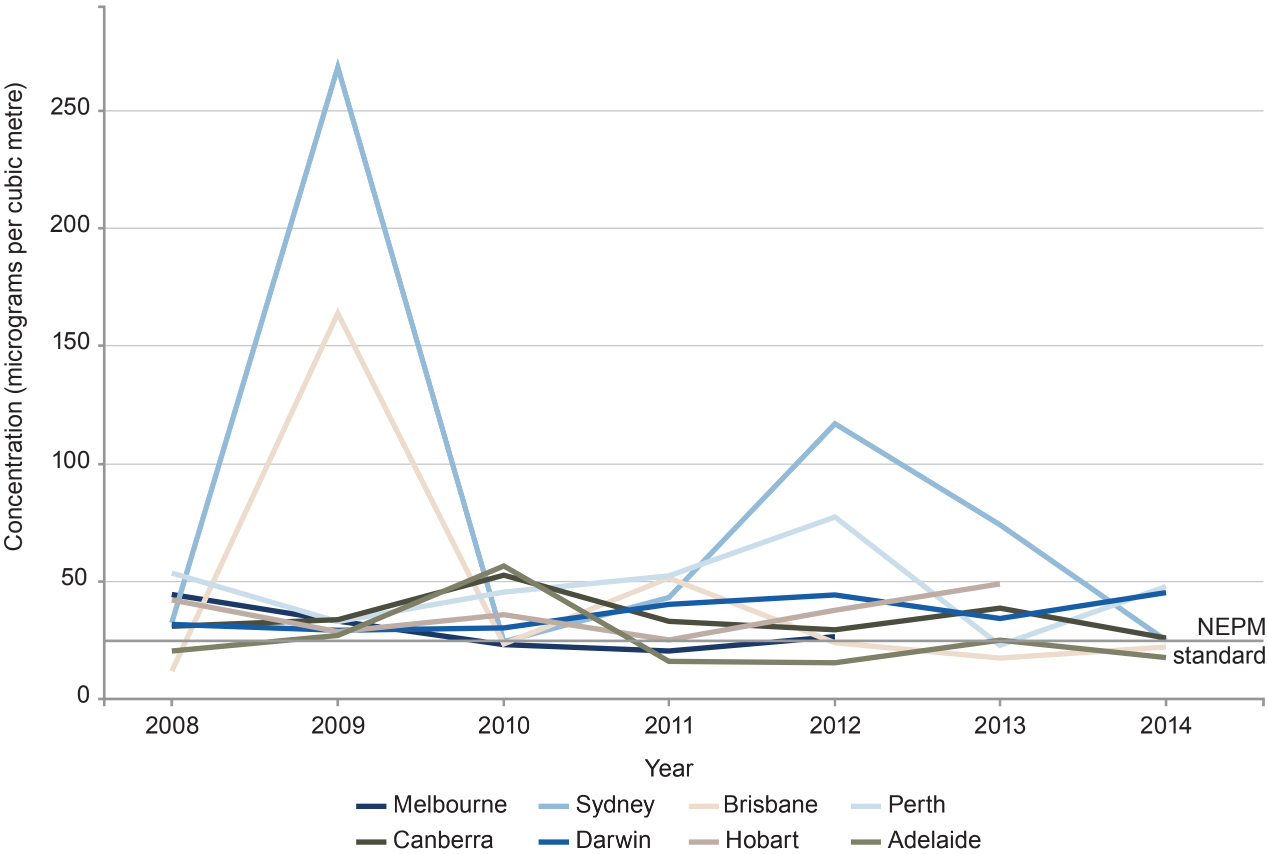


Figure ATM34 Capital cities' highest daily average $PM_{2.5}$ concentrations, 2008–14

Box ATM11 Characterising fine particle pollution in the upper Hunter Valley

When elevated concentrations of particulate matter of less than 2.5 microns ($PM_{2.5}$) are measured, it is important to understand the source of the particles to be able to control them. The Upper Hunter Air Quality Monitoring Network (UHAQMN) regularly measures elevated $PM_{2.5}$ concentrations in Muswellbrook and Singleton during winter. Because there are multiple sources of $PM_{2.5}$, including mining, coal-fired power generation, diesel vehicles, road and rail transport, solid fuel heaters and prescribed burning, the New South Wales Office of Environment and Heritage (OEH) and the New South Wales Ministry of Health commissioned a research study to better understand the composition and likely sources of fine particles that the populations in Muswellbrook and Singleton are exposed to.

The Upper Hunter Valley Fine Particle Characterisation Study (Hibberd et al. 2013) was undertaken at the UHAQMN sites in Singleton and Muswellbrook for the whole of 2012, with samples collected across 24 hours every third day. The samples were analysed using a range of techniques to determine concentrations of organic carbon, elemental carbon, soluble ions (including chloride, nitrate, sulfate, ammonium and sodium), levoglucosan and mannosan (markers for wood smoke); elemental composition; black carbon; and gravimetric mass.

The chemical composition of all the samples from each site was analysed using a mathematical technique called positive matrix factorisation (PMF), which is widely applied internationally for identifying sources contributing to ambient pollution. In the first step, the PMF statistical technique is applied to identify

Box ATM11 (continued)

correlations between the concentrations of individual chemical species, grouping correlated species into 'factors'. Factors have distinct chemical patterns or fingerprints. In this study, 8 factors were identified, with this number of factors found to provide the best explanation of the measured data. Further analysis then identified the most likely source of emissions identified in each factor and the contribution that each source makes to the total $PM_{2.5}$ concentrations.

Table ATM6 lists the PMF factors identified based on the dominant sources identified in their fingerprints. The contribution of each factor to total annual $PM_{2.5}$ concentrations measured at Singleton and Muswellbrook is also provided.

Table ATM6 Factors identified in $PM_{2.5}$, and their relative contributions and potential sources

Factor	Contribution of factor to total annual $PM_{2.5}$ mass at Muswellbrook	Contribution of factor to total annual $PM_{2.5}$ mass at Singleton	Potential source(s)
Wood smoke	30 ± 3%	14 ± 2%	Domestic wood heaters
Secondary ammonium sulfate	17 ± 2%	20 ± 2%	Occurs when gaseous sulfur dioxide emitted to the atmosphere during combustion of fossil fuels (e.g. power stations or motor vehicles) oxidises in the air, in the presence of sunlight, to form sulfuric acid. Ammonia that is emitted from biological production, such as livestock wastes and fertiliser, neutralises the sulfuric acid to produce ammonium sulfate particles
Pollutant-aged sea salt	13 ± 2%	18 ± 3%	Sea salt that has reacted with pollutants, especially from fossil fuel combustion (SO_2 and NO_2)
Biomass smoke	12 ± 2%	8 ± 2%	Bushfires, hazard reduction burns
Soil dust	11 ± 1%	12 ± 2%	Soil dust, fugitive coal dust
Vehicles/industry	8 ± 1%	17 ± 2%	Vehicles and industry. Vehicle emissions include fuel combustion emissions, and those from brake and tyre wear
Secondary nitrate	6 ± 1%	3 ± 2%	Secondary particles formed by photochemical reactions in the atmosphere with nitrate originating from NO_x emitted from fossil fuel combustion in vehicles, industry, nonroad diesel equipment, etc.
Fresh sea salt	3 ± 1%	8 ± 1%	Sea salt aerosol formed by waves breaking in the open ocean and from coastal surf breaks. The small particles can be transported hundreds of kilometres inland

NO_x = nitric oxide and/or nitrogen dioxide; NO_2 = nitrogen dioxide; $PM_{2.5}$ = particular matter less than 2.5 microns; SO_2 = sulfur dioxide

Box ATM11 (continued)

The annual variation in the contribution of the various factors is shown in Figure ATM35 for Muswellbrook. $PM_{2.5}$ levels are higher in the cooler months of the year, from May to October, with wood smoke the dominant contributor: an average of 62 per cent in winter compared with 0 per cent in summer. This is because of emissions from local domestic wood heaters, and the light winds and shallow inversions that are common on cold winter nights, leading to the build-up of pollution levels. In Singleton, wood smoke contributed an average of 38 per cent to the observed winter $PM_{2.5}$ concentrations.

In summer, secondary sulfate and pollutant-aged sea salt are the dominant factors. This is because of the higher contribution of fossil fuel combustion–related particles and sea salt during these months, both of which represent large-scale regional sources.

Results from this type of study provide communities with scientific information about what the fine particles are in their local environment. They also add to the evidence base that governments rely on to inform policies and better target programs aimed at reducing fine particle pollution.

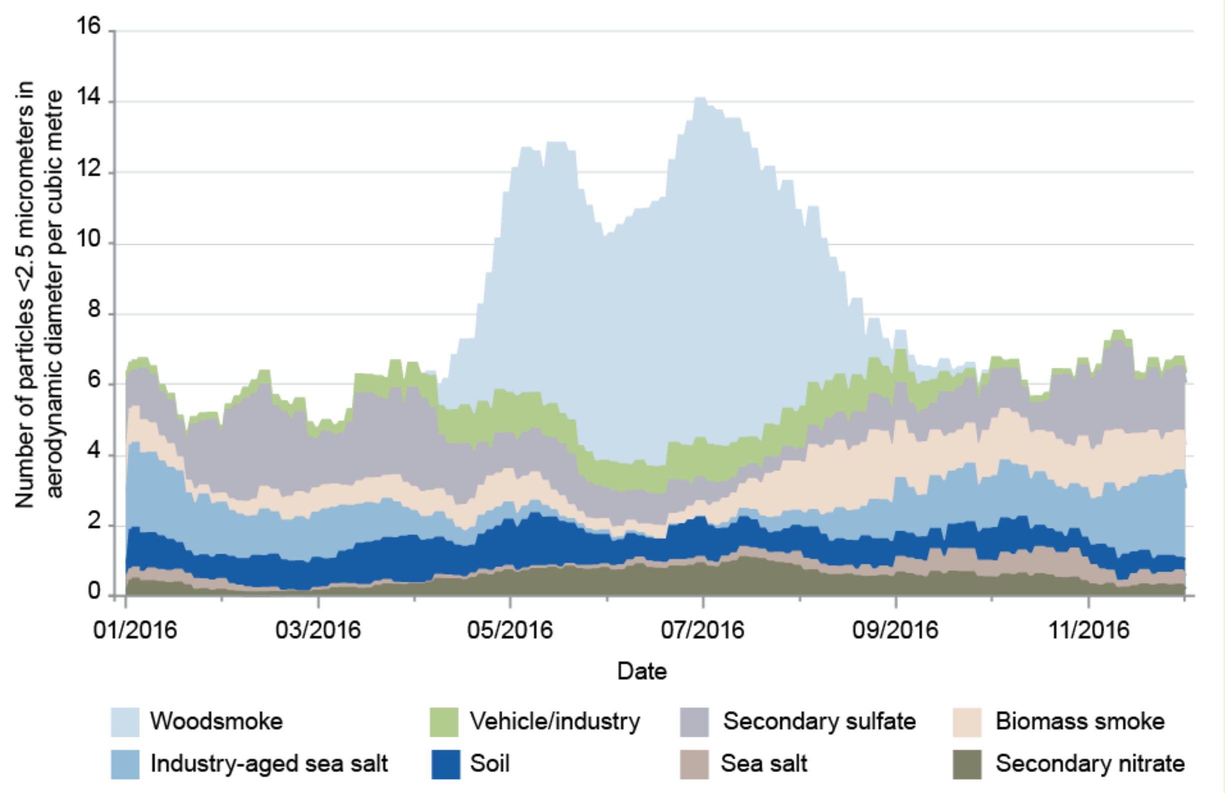


Figure ATM35 Annual variation (smoothed 31-day running average) in the composition of $PM_{2.5}$ at Muswellbrook, 2012

Source: Hibberd et al. (2013)

Ozone

Ozone is a secondary pollutant formed through the interaction of VOCs (see Volatile organic compounds) and nitrogen oxides (NO_x). The AQI for ozone in all capital cities was deemed 'good' from 1999 to 2008, and remained steady during this time. Only Canberra had ozone levels that were decreasing, but this result was based on limited evidence. Maximum levels of ozone in the capital cities have remained stable since SoE 2011. Sydney continues to have the greatest number of exceedances of the 4-hour ozone standard (Figure ATM36) and did not meet the 4-hour standard in 4 of the 5 years from 2010 to 2014 (note that the standard allows 1 exceedance). The past 5 years of the Melbourne timeseries show the trend increasing. The highest concentration, of 0.114 ppm, was recorded in 2014, but this was a single exceedance, and the standard has been met in Melbourne since 2010. Measurements of ozone in Canberra are included for the first time in this plot and were below the standard at all times.

Sulfur dioxide

Sulfur dioxide is not discussed in SoE 2016, because there has been little change since SoE 2011. Values in the capital cities are well below the Air NEPM standards. Exceedances of the 1-hour standard continue to be recorded more than 20 days per year in Port Pirie and Mount Isa because of emissions from ore smelting facilities. Annual maximum 1-hour concentrations are generally 3–4 times the 0.20 ppm standard. The Nyrstar Port Pirie Transformation Project planned for completion in 2017 is designed to reduce maximum emissions by a factor of 5 and average emissions by a factor of almost 10, which should lead to compliance with the Air NEPM.

Volatile organic compounds

VOCs are a group of carbon-based chemicals that easily evaporate at room temperature. Many common household materials and products, such as paints and cleaning products, give off VOCs. Common VOCs include acetone, benzene, ethylene glycol, formaldehyde, methylene chloride, perchloroethylene, toluene and xylene. Different VOCs have different health effects, and range from those that are highly toxic to those with no known health effect. Breathing low levels of VOCs for long periods of time may increase some people's risk of health problems. Several studies suggest that exposure to VOCs may make symptoms worse in people who have asthma or are particularly sensitive to chemicals. VOCs particularly affect indoor air quality—concentrations of many VOCs are consistently higher indoors (up to 10 times higher) than outdoors (US EPA 2016). Some VOCs are known to be air toxics (see Air toxics).

Sources of human-made VOCs in 2013–14 have changed little since 2009–10. Figure ATM37 shows the proportions of VOC emissions from motor vehicles, burning, industry, and commercial and domestic sources.

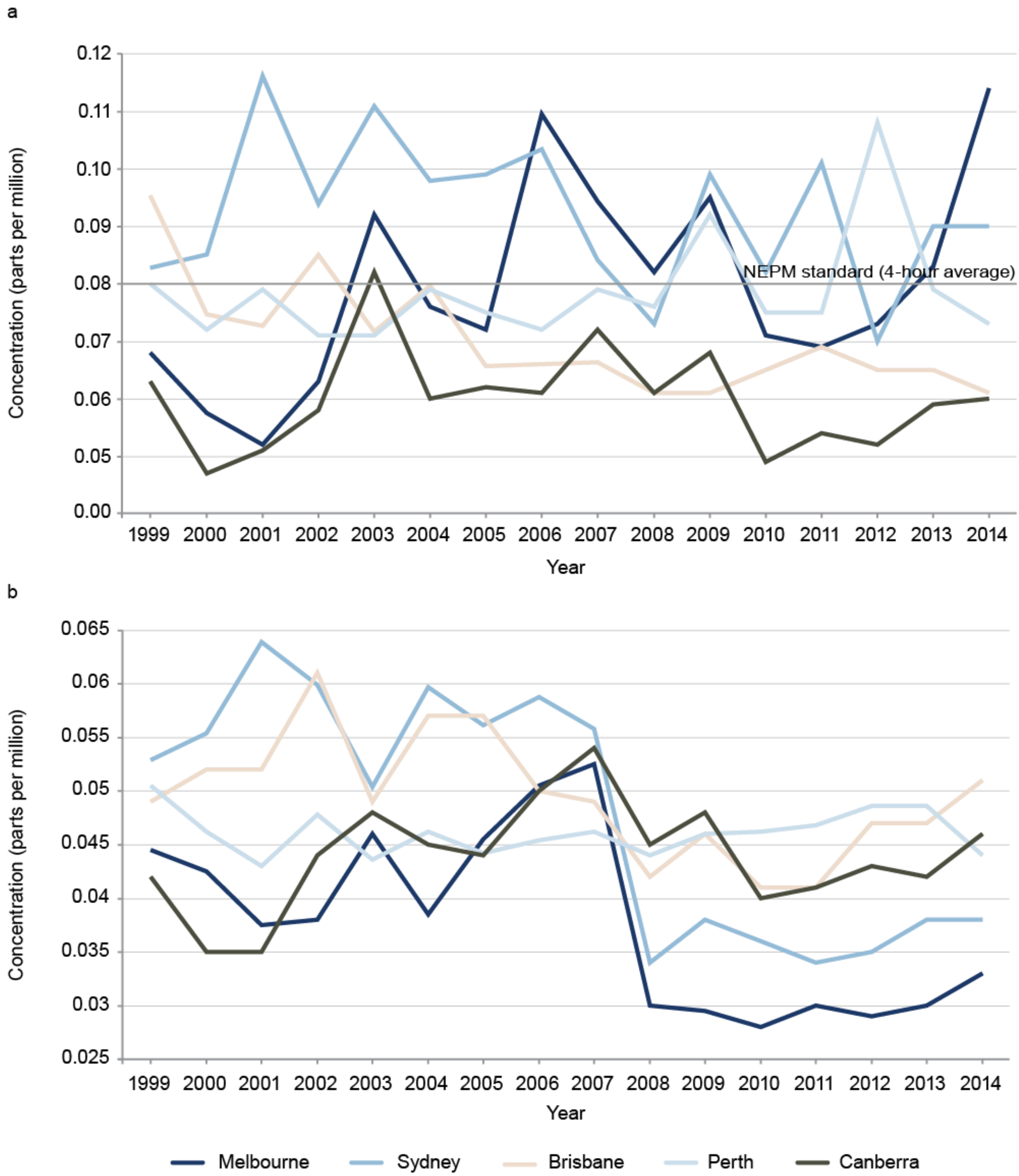


Figure ATM36 Ozone concentrations, major cities, 1999–2014: (a) maximum 4-hour averages; (b) 95th percentile 4-hour averages

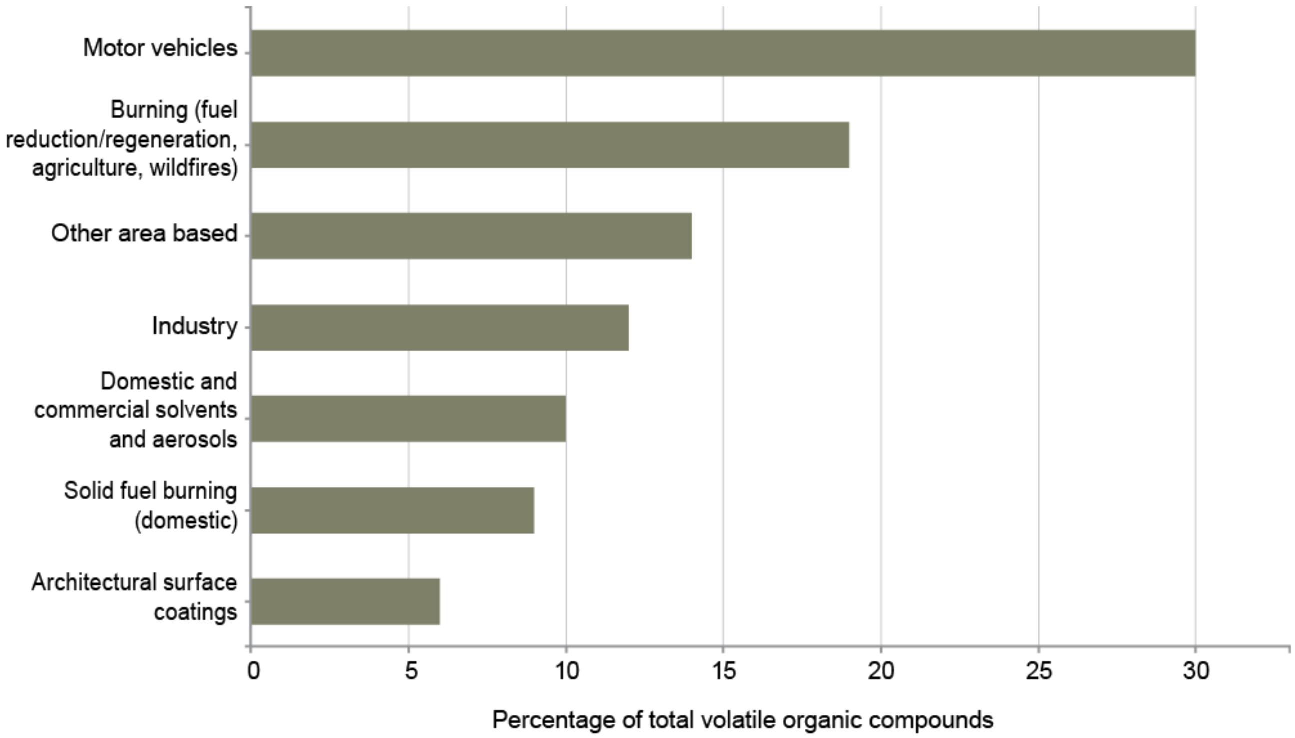


Figure ATM37 Sources of volatile organic compounds, 2013–14

Air toxics

Air toxics are pollutants that are usually present in ambient air in relatively low concentrations, but have characteristics such as toxicity or persistence that make them hazardous to human, plant or animal health. Some are known or suspected carcinogens, or cause birth defects or developmental, respiratory and immune system problems (Box ATM12). They include a diverse range of pollutants, including volatile and semivolatile organic compounds, and heavy metals. Air toxics are formed as products of combustion, as volatile emissions from paints and adhesives, and from various industrial processes.

The Air Toxics NEPM, established in 2004 for an initial group of pollutants (formaldehyde, toluene, xylene and polycyclic aromatic hydrocarbons), benchmarks monitoring investigation levels that, if exceeded, require further investigation. The mid-term review of the Air Toxics NEPM was reported in SoE 2011 and suggested that most of the pollutants were below the monitoring investigation levels. Since then, air toxics have been measured by the states and territories as needed, focusing on locations with significant sources of air toxics, such as areas with highly trafficked roads, clustered small to medium enterprises, high levels of wood heater use, and the presence of multiple sources, including major industry. For example, the Queensland Government monitors benzene, toluene, xylene and formaldehyde levels in south-east Queensland and Gladstone; the Victorian Government measured air toxics at the Tullamarine landfill in Victoria (EPA Vic 2011).

Box ATM12 Persistent organic pollutants in Australian air

Persistent organic pollutants (POPs) are semivolatile chemicals that resist degradation. Once in the environment, they can cycle through water, soil and air, ultimately to bioaccumulate in humans and other species. Exposure to POPs can lead to serious health effects, including certain cancers, birth defects, and dysfunctional immune and reproductive systems. The removal of POPs from the environment is the goal of the Stockholm Convention on Persistent Organic Pollutants, a global treaty to:

> *Protect human health and the environment from chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of humans and wildlife, and have harmful impacts on human health or on the environment.*

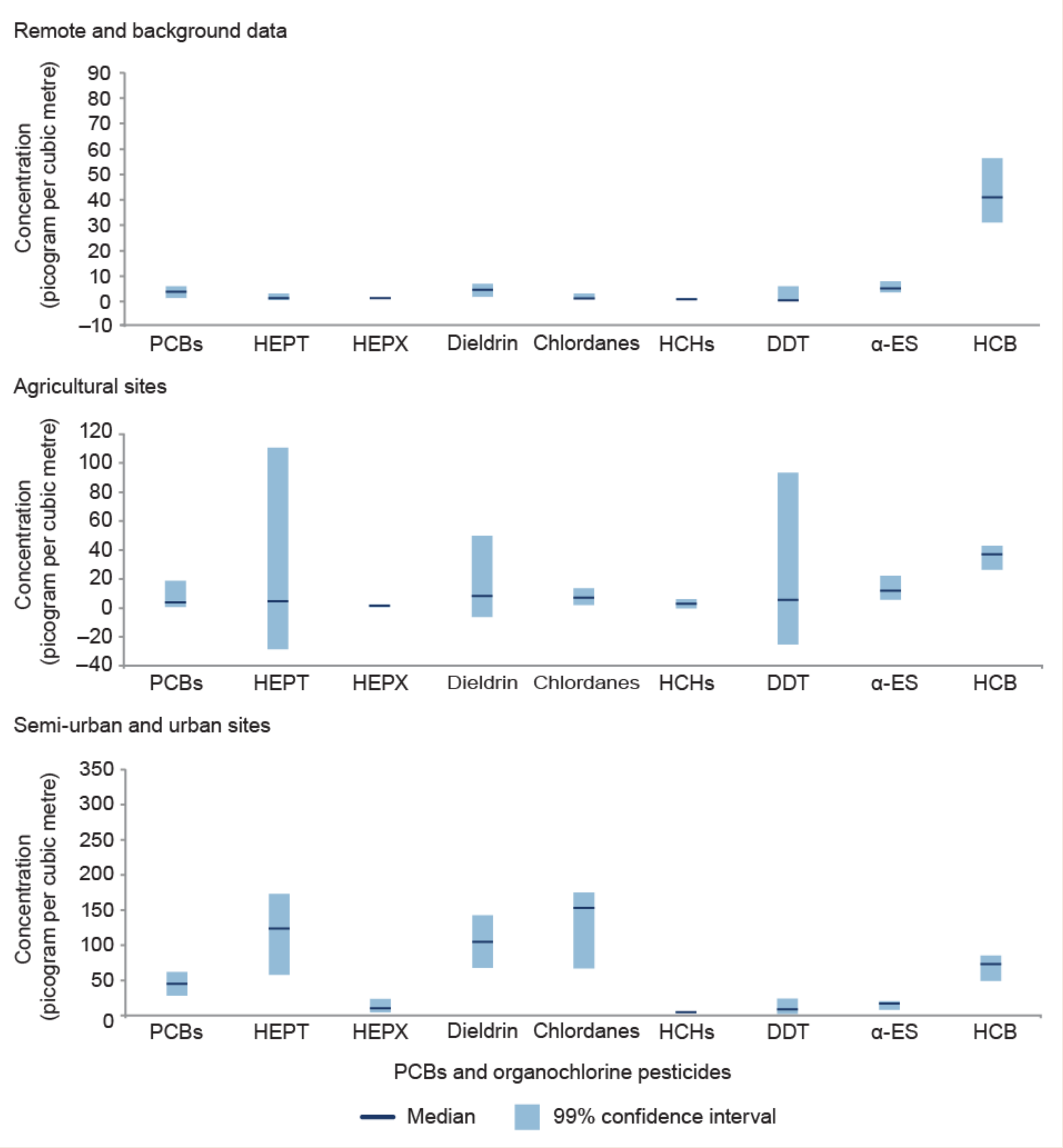
The Stockholm Convention requires the elimination, restriction or reduction in unintentional production of 27 compounds that have been used as pesticides, fire retardants and lubricants.

The effectiveness of the Stockholm Convention has been assessed using measurements from 2 Australian networks. Between 2011 and 2014, concentrations of POPs in air were measured at 11 locations around Australia, contributing to phase 1 of the National Monitoring of Hazardous Substances in Air Program supported by the Australian Government Department of the Environment and Energy, and CSIRO. These sites were chosen to represent regional background concentrations and some urban locations, and the data were reported to the Seventh Meeting of the Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants in 2014, in the Second Regional Monitoring Report for Western Europe and Other States Group. In addition, a nationwide passive air sampling campaign, supported by the department and the National Research Centre for Environmental Toxicology, recorded concentrations of POPs in Australia's atmosphere in 2012 at remote, agricultural, semi-urban and urban locations (Wang et al. 2015).

During 2012, both studies showed that overall concentrations of all POPs were lower at background sites than at agricultural, semi-urban or urban sites. Concentrations of polychlorinated biphenyls (PCBs—used in industry as heat exchange fluids; in electric transformers and capacitors; and as additives in paint, carbonless copy paper and plastics) were higher in urban locations, whereas concentrations of pesticides were generally higher at agricultural sites (Figure ATM38).

The organochlorine pesticide endosulfan, which was widely used in Australia for the control of some insects and mites in crops, particularly cotton, showed a major decrease in concentration during 4 years of monitoring at all sites in the National Monitoring of Hazardous Substances in Air Program (Figure ATM39). The dramatic decrease in endosulfan reflects the ban on the use of endosulfan in Australia, which came into effect in 2010. This is an excellent example of the ability of a comprehensive monitoring program to quantify the effectiveness of actions taken to reduce POPs in the environment.

Box ATM12 (continued)



α-ES = alpha endosulfan; DDT = dichlorodimethyltrichloroethane; HCB = hexachlorobenzene; HCH = hexachlorohexane; HEPT = heptachlor; HEPX = heptachlor epoxide; PCB = polychlorinated biphenyl
Source: Wang et al. (2015)

Figure ATM38 Concentrations of polychlorinated biphenyls and selected organochlorine pesticides in air at sites with different land uses

Box ATM12 (continued)

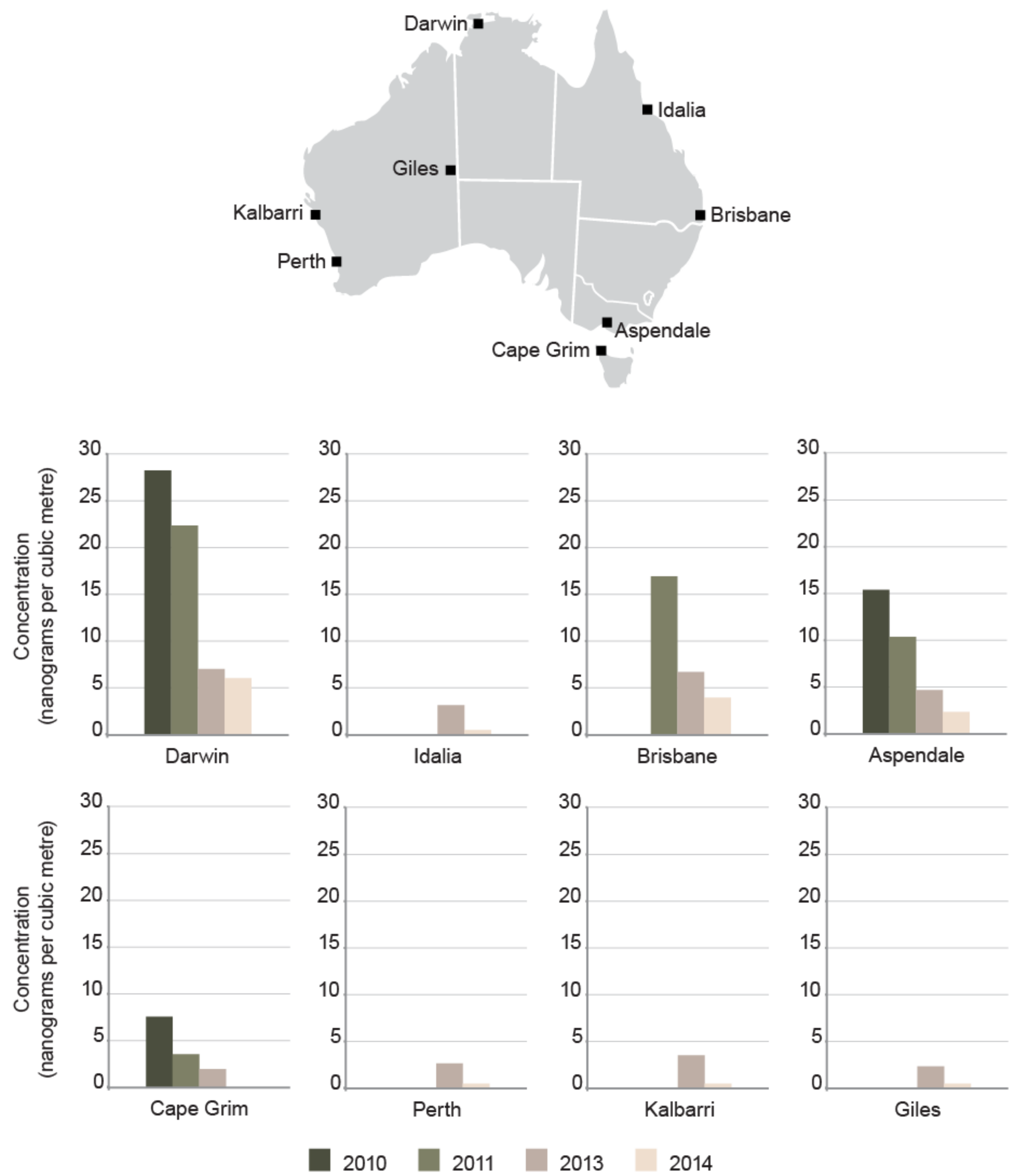


Figure ATM39 Endosulfan concentrations at study sites (Darwin, Idalia, Brisbane, Aspendale, Cape Grim, Perth, Kalbarri, Giles), 2010, 2011, 2013, 2014

Box ATM13 2016 ambient air assessment method

For this report, a qualitative assessment was made of ambient air quality in the 8 state and territory capitals, and a small number of major regional or industrial centres, using the same procedure as for the 2011 state of the environment report (SoE 2011).

Currently, no central repository of air quality data exists in Australia, so the data had to be obtained from each jurisdiction, because they were not always publicly available. There is a need for the Bureau of Meteorology to develop the National Air Quality Data Service as part of the National Clean Air Agreement. This will provide researchers and the community with much better access to air quality data.

The assessment was restricted to 3 of the 7 pollutants for which national health-based standards have been set: photochemical oxidants (as ozone), and coarse and fine particulate matter (as PM_{10} and $PM_{2.5}$, respectively). These were chosen as key pollutants because their concentrations, at times, are close to or exceed the standards, and because of their potential impact on human health (e.g. WHO 2013).

The approach is based on the characterisation of an airshed from 2009 to 2014 using its worst performing compliance station (monitoring site). These compliance stations are established in accordance with an approved National Environment Protection Measure (NEPM) monitoring plan, and are generally sited to be indicative of air quality experienced by the general population in the region. Most large regional cities have only one NEPM monitoring station, and most monitor particles but not ozone, since they lack the scale of industry and traffic likely to give rise to ozone as a secondary pollutant. In each state, the regional cities selected for analysis of PM_{10}, $PM_{2.5}$ and ozone (where this is monitored) were the worst performing in the state.

Ozone levels were evaluated against the 4-hour exposure standard of 0.08 ppm rather than the 1-hour standard (0.10 ppm), because the 4-hour standard is more likely to give a better indication of the impact on the general population, rather than on sensitive individuals affected by acute (shorter-term) events.

For each selected station, year and pollutant, the monitoring data were converted into air quality index (AQI) values, which express the measured concentration as a percentage of the standard. An AQI of 100 means that the pollutant is present in the air at the level of the standard. These AQIs were then allocated to one of the 5 qualitative categories (very good 0–33, good 34–66, fair 67–99, poor 100–149, and very poor 150+) commonly used by Australian environment protection agencies to report air quality.

These yearly percentage distributions were used as the basis for assigning an overall AQI for each pollutant at each station using the criteria set out in Table ATM7. The assessment was compared with that given in SoE 2011 to assess the trend. If the parameter was not assessed in 2011 (e.g. $PM_{2.5}$), the trend was based on results from 2009 to 2014.

Table ATM7 Criteria for assigning overall air quality index (AQI)-based qualitative categories

Overall category	Annual distribution of AQI values				
	Very good (%)	Good (%)	Fair (%)	Poor (%)	Very poor (%)
Very good	>50	>20	<10	<10	<5
Good	>20	>30	<20	<20	<10
Fair	<10	<20	>30	>20	<10
Poor	<10	<20	<20	>30	>20
Very poor	<5	<10	<10	>20	>50

Box ATM13 (continued)

A summary of the results is presented in assessment summaries 5 to 9.

Supplementary rules for assessing overall AQI were as follows:

- If the percentage very good is greater than 45 and is also greater than the percentage good, the assessment grade is very good.
- If the percentage good is greater than 75, the percentage very good can be as low as 0 and the assessment grade will still be good.
- If the assessment grade has stayed the same between the 2011 and 2016 reports, but the frequency of percentages within the grade has increased, the trend is set to 'improving' to reflect the increase.

National Environment Protection Measure for Ambient Air Quality monitoring station, Newcastle, New South Wales

Photo by Mark Hibberd

Assessment summary 5

Metropolitan cities' scorecard for ozone, NEPM 4-hour standard, based on analysis of air quality index values 1999–2014[a]

Component	Summary	Assessment grade (Very poor / Poor / Fair / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Adelaide—ozone (4-hour average)	Average percentage frequency distribution: very good 49; good 50; fair 1; poor 0; very poor 0	Good ↗	●	●	◆
Brisbane—ozone (4-hour average)	Average percentage frequency distribution: very good 31; good 65; fair 4; poor <1; very poor 0	Good —	●	●	◆
Canberra—ozone (4-hour average)	Average percentage frequency distribution: very good 38; good 61; fair 1; poor 0; very poor 0	Good —	●	●	◆
Darwin—ozone (4-hour average)	Average percentage frequency distribution: very good 72; good 27; fair 1; poor <1; very poor 0 Note: Darwin is a new entry in SoE 2016. Data are based on 2011–14	Very good ?	●	◒	X
Melbourne—ozone (4-hour average)	Average percentage frequency distribution: very good 94; good 6; fair 0; poor 0; very poor 0	Very good ↗	●	●	◆
Perth—ozone (4-hour average)	Average percentage frequency distribution: very good 67; good 32; fair <1; poor <1; very poor 0	Very good ↗	●	●	◆
Sydney—ozone (4-hour average)	Average percentage frequency distribution: very good 63; good 37; fair 0; poor 0; very poor 0	Very good ↗	●	●	◆

a Darwin began measuring ozone in March 2011.

Assessment summary 6

Metropolitan cities' scorecard for particles (PM_{10}), NEPM 24-hour standard, based on analysis of air quality index values, 1999–2014

Component	Summary	Assessment grade (Very poor / Poor / Fair / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Adelaide—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 59; good 37; fair 3; poor <1; very poor <1	Very good ↗	●	●	◆
Brisbane—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 69; good 29; fair 1; poor <1; very poor <1	Very good ↗	●	●	◆
Canberra—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 85; good 13; fair 2; poor <1; very poor <1	Very good ↗	●	●	◆
Darwin—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 50; good 38; fair 10; poor 2; very poor <1	Very good —	●	●	◆
Hobart—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 77; good 22; fair 1; poor <1; very poor 0	Very good ↗	●	●	◆
Melbourne—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 51; good 42; fair 5; poor 1; very poor <1	Very good ↗	●	●	◆
Perth—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 54; good 43; fair 3; poor <1; very poor <1	Very good ↗	●	●	◆
Sydney—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 58; good 38; fair 3; poor <1; very poor <1	Very good ↗	●	●	◆

Assessment summary 7

Metropolitan cities' scorecard for particles ($PM_{2.5}$), NEPM 24-hour standard, based on analysis of air quality index values, 2009–14[a]

Component	Summary	Assessment grade (Very poor / Poor / Fair / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Adelaide—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 71; good 29; fair <1; poor <1; very poor 0	Very good ↗	●	●	X
Brisbane—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 91; good 8; fair 1; poor <1; very poor <1	Very good —	●	●	X
Canberra—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 77; good 17; fair 5; poor 1; very poor <1	Very good ↙	●	●	X
Darwin—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 58; good 29; fair 10; poor 3; very poor <1	Very good ↙	●	●	X
Hobart—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 78; good 17; fair 5; poor 1; very poor <1	Very good ↗	●	●	X
Melbourne—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 69; good 27; fair 3; poor 1; very poor <1	Very good —	●	●	X
Perth—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 68; good 30; fair 1; poor <1; very poor <1	Very good ↙	●	●	X
Sydney—$PM_{2.5}$ (24-hour average)	Average percentage frequency distribution: very good 64; good 32; fair 3; poor <1; very poor <1	Very good ↙	●	●	X

a Darwin began measuring $PM_{2.5}$ in 2011. Melbourne Alphington station measured every 3 days until February 2014. Assessment trend is determined from trend during assessment period.

Assessment summary 8

Regional cities' scorecard for ozone, NEPM 4-hour standard, based on analysis of air quality index values, 1998–2014[a]

Component	Summary	Assessment grade (Very poor / Poor / Fair / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
New South Wales: Kembla Grange—ozone (4-hour average)	Average percentage frequency distribution: very good 89; good 11; fair 0; poor 0; very poor 0				
Victoria: Moe/ Traralgon—ozone (4-hour average)	Average percentage frequency distribution: very good 99; good 1; fair 0; poor 0; very poor 0				

a This period includes the 2014 Hazelwood mine fire, which affected the Victorian towns of Moe and Traralgon. The NEPM site at Moe was discontinued in quarter 4 of 2009.

Assessment summary 9

Regional cities' scorecard for particles (PM_{10}), NEPM 24-hour standard, based on analysis of air quality index values, 1999–2014

Component	Summary	Assessment grade (Very poor / Poor / Fair / Good / Very good)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
New South Wales: Wagga Wagga—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 49; good 40; fair 8; poor 2; very poor 1				
Queensland: Mackay—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 35; good 60; fair 4; poor 1; very poor <1				
South Australia: Port Pirie—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 61; good 34; fair 4; poor 1; very poor <1				
Tasmania: Launceston—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 75; good 22; fair 3; poor <1; very poor 0				
Victoria: Geelong—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 51; good 42; fair 6; poor 1; very poor <1				
Western Australia: Bunbury—PM_{10} (24-hour average)	Average percentage frequency distribution: very good 51; good 46; fair 2; poor <1; very poor <1				

Recent trends

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

Grades

- **Very good:** Air quality is considered very good, and air pollution poses little or no risk
- **Good:** Air quality is considered good, and air pollution poses little or no risk
- **Fair:** Air quality is acceptable. However, there may be health concerns for very sensitive people
- **Poor:** Air quality is unhealthy for sensitive groups. The general population is not likely to be affected in this range
- **Very poor:** Air quality is unhealthy, and everyone may begin to experience health effects. People from sensitive groups may experience more serious health effects

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Effectiveness
of management of Australia's air quality

At a glance

Australia has had national standards and goals for ambient air quality for almost 20 years—the National Environment Protection Measure for Ambient Air Quality (Air NEPM). These are based on strong empirical evidence about the health impacts of major pollutants. However, revision of the standards has been slow, despite new evidence that many pollutants do not have a threshold below which adverse health effects do not occur, and much work done by several groups and parties.

During the past 30–40 years, state and territory environment protection agencies have employed a variety of regulatory measures (including works approval, licensing and notices) to control and greatly restrict emissions of air pollutants from industrial and commercial sources. More recently, nonregulatory measures (such as codes of practice, market-based mechanisms and cleaner production incentive schemes) have been increasingly used to complement regulatory controls. In some jurisdictions, local government has a role in controlling emissions (mainly of particles and odour) from commercial sources. Local government also tends to be the main tier of government responding to complaints at the neighbourhood level about smoke from domestic wood heaters.

Although the size of the Australian vehicle fleet is continuing to grow (as are the distances travelled), exhaust emissions are expected to continue to decline during the next decade because of tighter national fuel and vehicle emissions standards, and the replacement of ageing vehicles with more efficient ones. There are national emissions standards for new vehicles, set in the Australian Design Rules, and fuel quality standards, both of which are established through Commonwealth legislation (the *Motor Vehicle Standards Act 1989* and the *Fuel Quality Standards Act 2000*, respectively). However, non-exhaust emissions are likely to continue to grow and become a larger proportion of particulate matter emissions. Non-exhaust emissions include particulate matter from brake, clutch, and road surface wear, as well as resuspension of these particles. State and territory authorities are responsible for enforcing compliance with emissions standards for vehicles, and Australian Government officials monitor and enforce compliance with fuel standards.

Management framework

Each level of government—Australian, state and territory, and local—plays a role in managing the impacts of air pollution by preventing or minimising air pollutant emissions. For the key air quality standards, the Australian, state and territory governments act cooperatively to set national objectives and develop the NEPMs, through the NEPC.

The Australian Government is responsible for emissions standards for new motor vehicles, motor vehicle fuel standards, the National Pollutant Inventory, the national response to climate change, and international obligations such as the International Convention for the Prevention of Pollution from Ships (commonly referred to as MARPOL).

State and territory governments are responsible for implementing NEPMs and other measures with appropriate legislation, policies and programs. They report on progress made in achieving the NEPM goals.

Local government authorities are generally responsible for managing air pollution from small businesses and domestic premises, and through their role in urban planning.

International agreements

Australia is party to several international agreements that aim to reduce the levels of harmful chemicals in the Australian environment. These chemicals can be harmful to human health and ecosystems.

The Stockholm Convention on Persistent Organic Pollutants is a global treaty that requires elimination, restriction or reduction in unintentional production of 27 compounds that have been used as pesticides, fire retardants and lubricants. These compounds can bioaccumulate in humans and other biota, and exposure to these compounds can lead to serious health effects. The Minamata Convention on Mercury is a global treaty to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds, using measures to control the supply and trade of mercury.

National Environment Protection Council

National air quality standards in Australia are set by the NEPC, whose current members are the Australian environment ministers. NEPMs include those for ambient air quality, air toxics, diesel vehicle emissions, and the National Pollutant Inventory. The NEPC is also responsible for assessing and reporting on the implementation and effectiveness of NEPMs. Performance against the Air NEPM is assessed at compliance stations located at sites representative of air quality likely to be experienced by the general population.

The Australian Government Department of the Environment and Energy currently provides operational support for the NEPC, following abolition of the NEPC Service Corporation on 1 July 2014. Six months earlier, the Council of Australian Governments revoked the Standing Council on Environment and Water, which was established after a 2010 review of the ministerial council system. This review had seen the dissolution of the Environment Protection and Heritage Council, which was established in 2001. The related restructuring of associated expert groups for the NEPC during the past 5 years, as well as regulatory reform agendas, have slowed progress on some air quality improvements that were foreshadowed in SoE 2011.

National standards

Australia has had national standards and goals for ambient air quality since 1998. The Air NEPM mandates a consistent approach to air quality monitoring, which has been applied by all states and territories, but—recognising the different legislative arrangements in each jurisdiction—does not dictate the means to be applied to achieve the goals. Performance against the standards and goals is published annually, but the single access point for these reports has not been maintained since the demise of the NEPC Service Corporation.

Responding to growing concern about particle and NO_x pollution from diesel vehicles, the National Environment Protection (Diesel Vehicle Emissions) Measure was established in 2001. Unlike the Australian Design Rules (ADRs), which set standards for new petrol and diesel vehicles, the Diesel Emissions NEPM targets in-service vehicles (which are a state or territory responsibility), providing a range of strategies for governments to reduce emissions, such as smoky vehicle programs, inspection and maintenance programs, and retrofit programs.

The national standards were developed based on strong empirical evidence about the health impacts of major pollutants, but new evidence has emerged during the past 20 years. A review of the NEPM was initiated in 2005, with the final report in 2011 recommending that, because new evidence showed that many pollutants do not have a recognised threshold for adverse health effects, there should be a shift in the focus of the NEPM to minimise the risk to population health from air pollution (NEPC 2011a,b). The review found that more benefit at less cost could be achieved through abatement of PM pollution than for any other pollutant, so this was set as the priority for review.

On 15 December 2015, Australia's environment ministers agreed that the advisory standards for $PM_{2.5}$ should become reporting standards and that an annual average standard for PM_{10} of 25 μg/m^3 should be added to the existing 24-hour standard. Recognising the health advantages of lower PM standards, they also agreed to aim to lower the $PM_{2.5}$ standards by 2025—from 25 to 20 μg/m^3 for the 24-hour average and from 8 to 7 μg/m^3 for the annual average. These changes were legislated in 2016 and are incorporated in the listing in Table ATM4.

To cope better with natural events that can contribute to exceedance of the standards, the 2016 NEPM changes introduced an exceptional event rule for episodes such as the major 2009 dust storm. Other natural particles, such as those of biogenic origin from emissions in the nearby Blue Mountains, can dominate the Sydney airshed during summer (Cope et al. 2014), and can make it difficult to achieve lower standards.

The 2011 review also prompted an investigation of options for introducing an exposure reduction framework (Bawden et al. 2012), after which the NEPC supported the development of an air quality 'exposure' metric and methodology (NEPC 2015). This has been incorporated into the 2016 Air NEPM changes. The review by the Air NEPM Expert Working Group of standards for ozone, nitrogen dioxide and sulfur dioxide is currently under way, led by the Environment Protection Authority Victoria, and is due to report in 2018.

National Pollutant Inventory

The National Pollutant Inventory (NPI) was established in 1999 as an NEPM. It is a public database that provides information on the types and amounts of 93 pollutants emitted to air (as well as to land and water) that have been identified as important because of their possible effects on human health and the environment. They include products of combustion (from burning petrol, diesel, coal, gas, etc.), VOCs, solvents and inorganic substances (e.g. metals, metal oxides).

Through its public accessibility, the NPI seeks to:

- increase public and industry understanding of environmental pollution
- track environmental progress
- promote continuous improvement by encouraging companies to look for ways to minimise their environmental impact, and assist government in identifying priorities for environmental decision-making.

Industrial facilities such as power stations, smelters and mines report on their annual emissions, which are estimated using NPI emissions estimation technique manuals.

Other emissions (referred to by the NPI as diffuse emissions) are estimated directly by the jurisdictions. They cover emissions from commercial activities such as bakeries and service stations, domestic activities such as domestic wood heaters and lawn mowing, motor vehicle emissions, and emissions from small industries that are not required to report individually. They are only reported for certain airsheds and gridded according to the needs of each jurisdiction.

The method for calculating the motor vehicle emissions inventory was revised in 2014 using COPERT Australia software (Computer Programme to calculate Emissions from Road Transport), and it was extended to be nationwide.

An NPI users' survey in 2014 produced recommendations to:

- develop a nationally consistent emissions dataset that allows direct comparison of emissions across jurisdictions and facilities, and with other national and international inventories (e.g. the National Greenhouse Gas Inventory)
- investigate more robust techniques for emissions estimation and compilation
- improve the comprehensiveness and quality of NPI data, particularly for diffuse emissions
- include relevant metadata
- integrate relevant new datasets with the NPI
- consider novel promotion activities to increase awareness of the NPI resource.

As discussed earlier, it is important to note that total annual emissions levels are not the same as exposure levels. The actual contribution of any individual source to population exposure (and thus health effects) is typically much larger for local sources, such as motor vehicles and domestic wood heaters, than for industrial sources (e.g. Caiazzo 2013). This is because motor vehicle and wood heater emissions are released close to ground level, and near where people live and work. In contrast, industrial emissions are generally separated from populated areas, and are typically emitted through vents and stacks with outlets well above ground level. For power stations, stacks are typically 200 metres tall. This means that such emissions are always significantly diluted before they reach the population.

Regional emissions inventories

The NPI contains data on annual emissions. This is useful for its intended purposes, but it is generally not suitable for urban or regional air quality modelling because of the absence of information about the temporal variation (diurnal or seasonal variation, or dependence on meteorology such as windblown dust) or the spatial distribution of diffuse emissions (vehicle, domestic, commercial).

Some jurisdictions have developed emissions inventories for their key airsheds, and use them to inform air quality management decisions and assess the effectiveness of regulation. These are based on a mixture of modelling and estimation techniques, with important quality control through verification studies. The most significant regional inventories are listed in Table ATM8. As model complexity increases, so does the need for information on more pollutant species in the inventories. For example, many $PM_{2.5}$ particles are secondary particles, which require good inventory information about their precursors if the models are to be used to determine the effectiveness of various policies for reducing $PM_{2.5}$ exposures.

Table ATM8 Regional emissions inventories in Australia

Factor	NSW GMR	Victoria	South-east Queensland	Perth	Adelaide
Base year	2008 (2013 update in progress)	2008, (2011 update in progress)	2000	Motor vehicles: 2005–07; other sources: 1998–99	Motor vehicles: 2006; other sources: 1998–99
All major sources included?	Yes	Not marine aerosol	Not fugitive windborne or marine aerosols or paved road dust	Not fugitive windborne or marine aerosols	Not biogenic/ geogenic sources
Secondary precursor pollutants?	Not elemental/ organic carbon	Yes	Not SO_3 or elemental/organic carbon	Not SO_3 or elemental/organic carbon	Not SO_3 or elemental/organic carbon
Suitable for urban/regional air quality modelling?	Yes	Yes	Yes	No spatial or temporal variation of emissions	No spatial or temporal variation of emissions

NSW GMR = New South Wales Greater Metropolitan Region (includes Sydney, Newcastle and Wollongong regions); SO_3 = sulfur trioxide
Source: Based on Table 5.1 in Bawden et al. (2012)

National Clean Air Agreement

In 2014, a National Clean Air Agreement (NCAA) was proposed, which, after a public consultation process, was agreed to by all Australian environment ministers on 15 December 2015 (Australian Government 2015c). The NCAA provides a framework to identify and prioritise specific air quality issues, and to develop effective and efficient policy. It acknowledges the importance of combining several strategic approaches: standards; emissions reduction measures; partnerships and cooperation; and better knowledge, education and awareness. The initial work plan includes reducing emissions from wood heaters, and nonroad spark-ignition engines and equipment, as well a range of other measures listed in Table ATM9.

Table ATM9 National Clean Air Agreement, initial work plan 2015–17

Strategic approach	Priority areas	Timeframe
Standards	Vary Air NEPM to strengthen particle reporting standards	Mid-2016 (completed)
	Review Air NEPM for sulfur dioxide, nitrogen dioxide and ozone towards strengthening the standards	Mid-2016
	Review *Fuel Quality Standards Act 2000*	Mid-2016
	Review Air Toxics and Diesel Vehicles NEPMs	2016
Emissions reduction measures	Reduce emissions from nonroad spark-ignition engines and equipment (decision RIS completed 2015)	Implement by 2017
	Reduce emissions from wood heaters (decision RIS completed 2015)	Implement by 2017
	Manage nonroad diesel engine and marine engine emissions	2016
Partnerships and cooperation	Explore partnerships with nongovernment stakeholders to positively influence air quality outcomes	Ongoing
	Improve exchange of information and experiences in implementing air quality management/monitoring tools across jurisdictions	Ongoing
Better knowledge, education and awareness	Improve access to reliable air quality information for researchers, policy-makers and the community:	
	• National Air Quality Data Service	Mid-2017
	• National Environmental Science Programme Clean Air and Urban Landscapes hub	2015–21
	Undertake National Pollutant Inventory reforms	2014–16
Priority setting	Establish and implement a priority-setting process and work plan	2015 start, ongoing

NEPM = National Environment Protection Measure; RIS = regulation impact statement
Source: DoE (2015c)

The National Environmental Science Programme has set aside $8.88 million over 6 years for a Clean Air and Urban Landscapes hub. The research is focused on building better, more livable cities, but some of the resources will be directed to strategic research to address air quality priorities. One of the first objectives is to provide comprehensive air quality monitoring in western Sydney to investigate sources of PM.

The Bureau of Meteorology is developing a central National Air Quality Data Service, to house the air quality data collected by the states and territories from their regulatory monitoring. At present, these data are held by the states and territories themselves, and are not always publicly available. The new service would enable the public to interrogate the database themselves, and use the information for their own research or other projects.

Management of sources of pollution

Industrial point sources

Environmental agencies in the states and territories are responsible for controlling pollutant emissions from large industrial point sources, such as power stations, refineries, smelters, manufacturing plants, cement works and abattoirs. Various regulatory measures (including works approvals, licences and notices), together with emissions monitoring and modelling, and enforcement programs, are used to prevent emissions from individual point sources affecting health or amenity at the local level. The regulatory measures also prevent such sources collectively leading to exceedance of national ambient standards at a larger scale.

Despite major gains in air quality achieved through improved pollution controls and cleaner forms of production, emissions from large industrial point sources still lead to some exceedances of ambient air quality standards in some centres, such as for sulfur dioxide in Port Pirie and Mount Isa (see also Box ATM14). The Port Pirie Transformation Project, slated for completion in 2017, is projected to halve the impact of lead and sulfur dioxide emissions from the smelter, and ensure that air quality standards are met.

Typical industrial point sources at Wagerup, Western Australia
Photo by Mark Hibberd

Box ATM14 Hazelwood mine fire

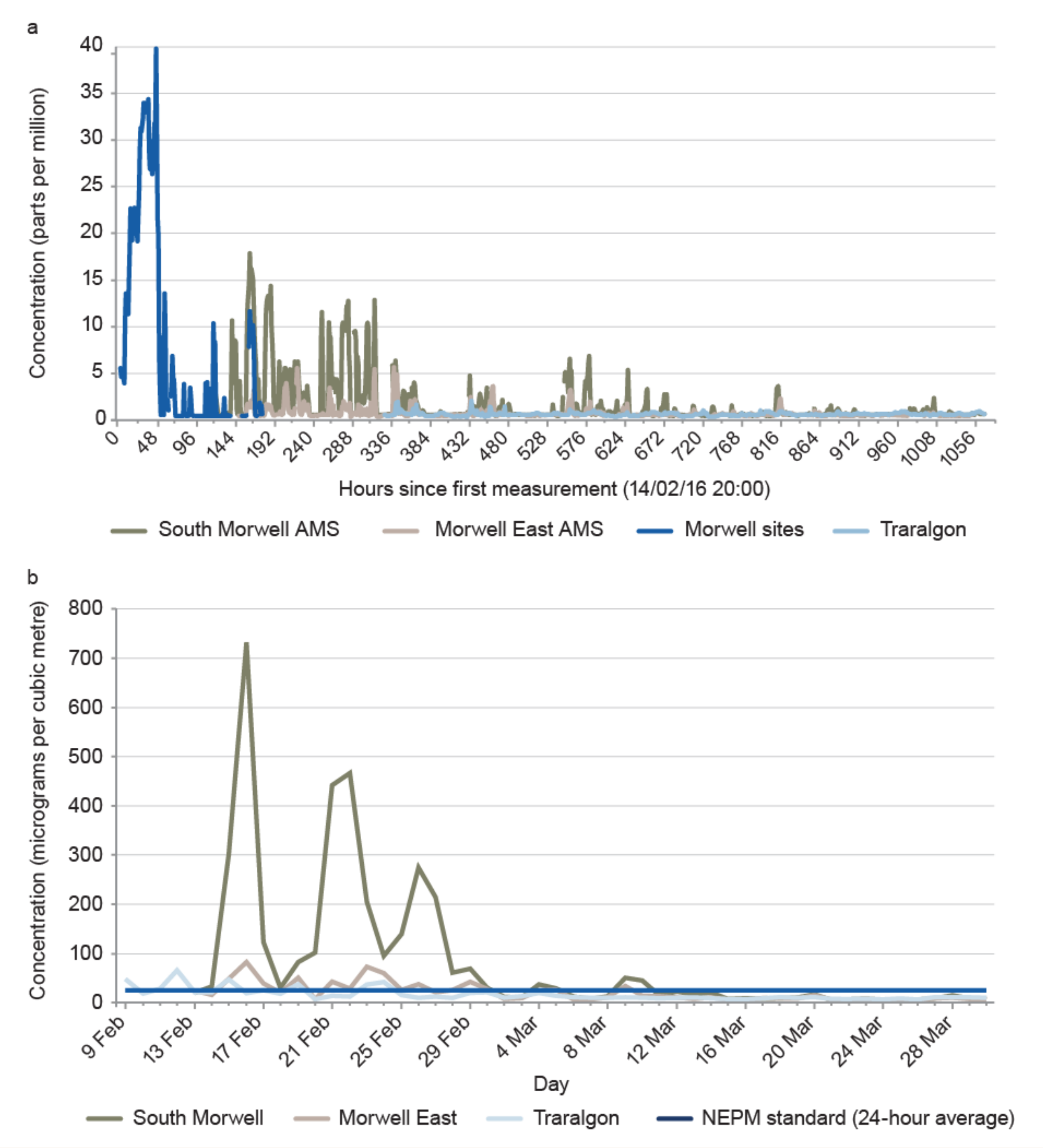
On 9 February 2014, embers from nearby bushfires burning in east Gippsland and other parts of the Latrobe Valley ignited a fire within an unused part of the Hazelwood open-cut coalmine in Victoria. The fire spread rapidly and extensively under strong south-westerly winds, causing a serious air pollution event that affected thousands of residents in nearby towns for many days. The fire was declared safe on 25 March 2014, having burned for 45 days.

Air quality monitoring undertaken onsite showed that smoke from the Hazelwood fire affected a wide area, especially the township of Morwell located just a few hundred metres from the fire. Pollutant concentrations were highly variable, with the highest concentrations occurring during south-westerly winds when the smoke from the fire was blown into the town of Morwell. Smoke was trapped within the lower boundary layer of the atmosphere where dispersion was minimal, causing elevated concentrations near the ground. Pollutant levels were significantly elevated in February, decreased in March once the fire abated and returned to background levels once the fire was declared safe at the end of March. At peak times, fine particulate matter ($PM_{2.5}$) and carbon monoxide concentrations exceeded national air quality standards. Despite a significant decrease in pollutant concentrations with distance, the national standards for PM were still exceeded in Traralgon, located approximately 13 kilometres from the fire (Figure ATM40).

In response to community concerns about the long-term health effects, the Victorian Department of Health and Human Services commissioned the Hazelwood Mine Fire Health Study. The study is looking at potential health outcomes (including respiratory and heart disease, cancer and mental health problems) for people who may have been affected by the smoke from the mine fire.

Smoke plume from the Hazelwood mine fire, Latrobe Valley, Victoria
Photo by Jason Choi

Box ATM14 (continued)



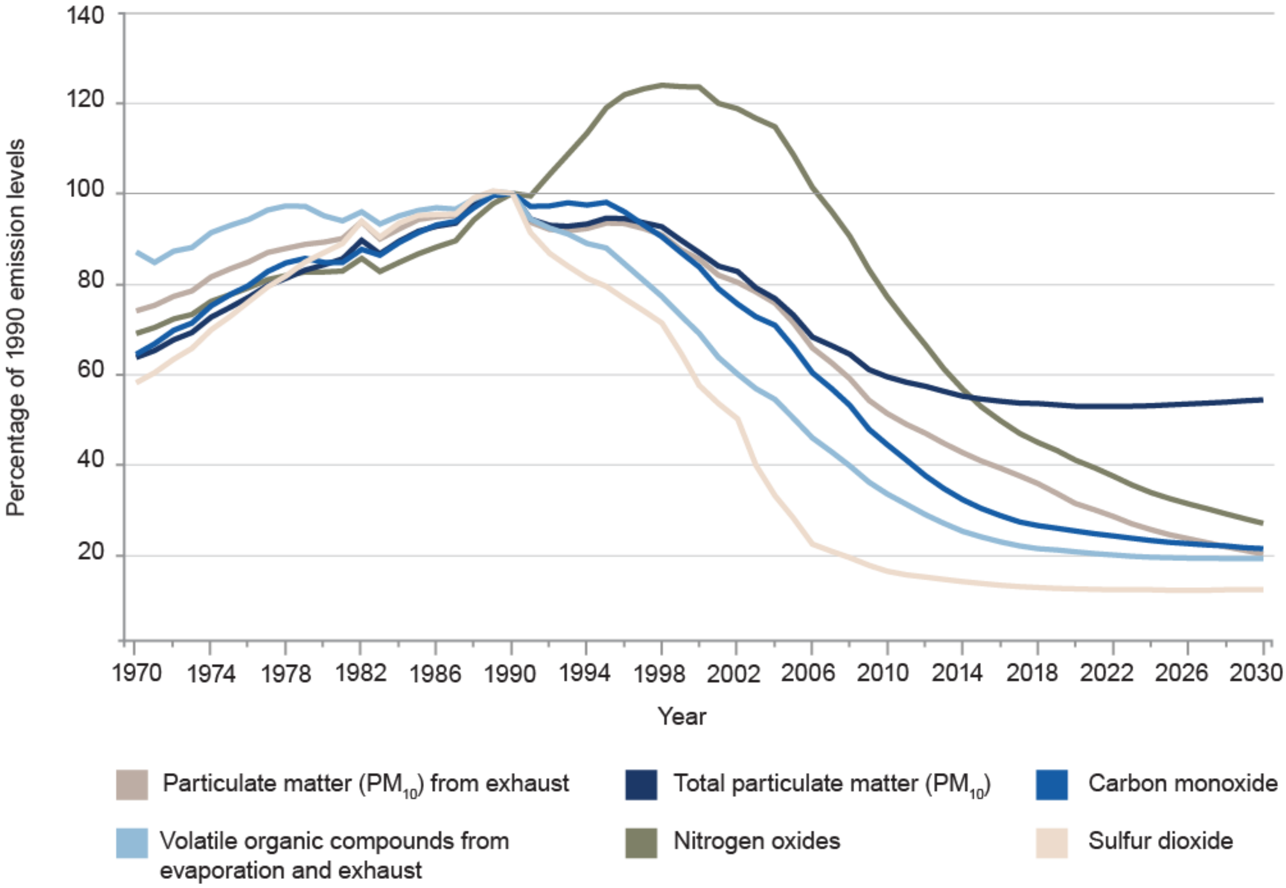
AMS = air monitoring station; NEPM = National Environment Protection Measure

Figure ATM40 Pollutant concentrations measured during the Hazelwood mine fire: (a) hourly carbon monoxide; (b) 24-hour fine particulate matter ($PM_{2.5}$)

Motor vehicles

In addition to the Air NEPM, the Australian Government plays an important role in achieving air quality goals through its powers to set emissions standards for new vehicles through ADRs and fuel quality standards. ADRs are established under the *Motor Vehicle Standards Act 1989*, and vehicle fuel quality standards are set through the *Fuel Quality Standards Act 2000*. A reform of the Motor Vehicle Standards Act was proposed in 2016 (DIRD 2016), with the stated aim of reducing regulatory burden and barriers, including any regulatory barriers limiting the uptake of energy-efficient and alternative energy technologies. A broader review of vehicle emissions began in 2015 with establishment of a Ministerial Forum on Vehicle Emissions (DIRD 2015) to examine ways to reduce the health and environmental impacts of motor vehicle emissions.

The nature and scale of the impact of motor vehicles on air quality in our major cities are generally well understood. Significant reductions in vehicular emissions followed the tightening of ADR emissions limits for carbon monoxide and hydrocarbons in 1986, and the national introduction of 3-way catalytic converters and unleaded fuel in the 1990s (Figure ATM41). These reductions have been maintained, despite increasing numbers of vehicles and distances travelled. In contrast, NO_x levels continued to rise throughout the 1990s because ADR NO_x limits were not tightened until 1997–99, when ADR 37-01 was introduced. This, combined with continued growth in numbers



Note: 'Particulate matter (PM_{10}) from exhaust' values in this graph refer solely to exhaust emissions; 'total particulate matter (PM_{10})' includes other vehicle-sourced particulates (e.g. road dust, brake and tyre wear, secondary sulfates). Total PM_{10} emissions from Australian road use (including wear particulates and secondary aerosols, and combustion PM) have plateaued and look set to increase in future.
Source: Bureau of Infrastructure, Transport and Regional Economics, 2015

Figure ATM41 Historical and projected trends in road transport emissions, 1970–2030 of vehicles and distances travelled, resulted in a lag of several years before improved emissions controls led to a plateauing of NO_x levels.

The Bureau of Infrastructure, Transport and Regional Economics has developed projections for metropolitan cities. These indicate continuing reductions in carbon monoxide, VOCs (evaporative and exhaust emissions), PM_{10} (exhaust emissions) and NO_x until 2030, because of the increasing proportion of newer vehicles that meet the latest ADR requirements for engine and emissions controls, and improved fuel standards. However, the projections are based on a 'business as usual' case—that is, continued economic and population growth, no domestic carbon price in place, no further emissions standards (after 2007–08 for diesel vehicles and 2008–10 for light-duty petrol vehicles), and only mid-range increases in petrol prices (based on International Energy Agency reference case projections). They do not factor in further reductions because of changing standards. For example, European emissions standards define acceptable limits for exhaust emissions of new vehicles sold in the European Union. The standards have been rolled out in stages since 1993; the stages are referred to as Euro 1 to Euro 6.

Since 1 November 2013, the tighter Euro 5 emissions standards for light vehicles applied to all new-model vehicles sold in Australia, with existing models to comply from 1 November 2016. Table ATM10 summarises the emissions limits for the Euro 4, 5 and 6 standards for light vehicles.

These improvements, together with those associated with the earlier introduction of the Euro 3 and Euro 4 standards, should continue to counter the effect of further growth in vehicle numbers and distances travelled. However, although the general outlook is therefore encouraging, it needs to be acknowledged that local vehicle pollution 'hotspots' continue to exist in our major cities. These are usually associated with road tunnels and very heavily trafficked roads, often carrying a significant proportion of heavy commercial vehicles through residential areas. A growing body of evidence shows that residents living on or near such roads experience not only loss of amenity, but also a range of adverse health effects.

Diesel-fuelled registered vehicles are an increasing fraction of all registered vehicles (up from 1.0 million in 1999 to 3.6 million, or 19.7 per cent, at 31 January 2015). These figures represent an increase of 10 per cent per year during the previous 5 years. The progressive tightening of diesel fuel standards is expected to contribute to a reduction in particle and NO_x levels over time by enabling the use of catalytic particle filters and NO_x adsorbers.

In 2015, it was found that the Volkswagen Group had installed software in 11 million diesel engines to circumvent emissions tests, leading to NO_2 emission rates 10–20 times greater than legally permitted in Europe and the United States. Oldenkamp et al. (2016) has estimated the public health consequences of these additional emissions, and calculated the value of life lost to be at least US$39 billion. The impact in Australia is not known, but the reported on-road emissions from these vehicles would have met the Euro 4 standard required for new vehicles in Australia until the end of 2013.

The average age of the total vehicle fleet has been steady at between 9.9 and 10.1 years in the 10 years to 2016. Campervans have the highest average age at 17.4 years (down from 17.8 in 2011), followed by heavy rigid trucks at 15.7 years (15.5 in 2011), whereas passenger vehicles have the lowest average age at 9.8 years (steady since 2011).

Table ATM10 Emissions standards for Euro 4, 5 and 6 light vehicles

Standard	Introduced in Europe	Mandated in Australia for all new light vehicles	Emission limits (g/km) for petrol/diesel engines		
			HCs	NO_x	PM
Euro 4	2005	1 July 2010	0.10/0.30	0.08/0.25	na/0.025
Euro 5	2011	1 November 2016	0.10/0.23	0.06/0.18	0.0045/0.0045
Euro 6	2014	To be determined	0.10/0.17	0.06/0.08	0.0045/0.0045

g/km = grams per kilometre; HCs = hydrocarbons; na = not applicable; NO_x = nitrogen oxides; PM = particulate matter
Note: Euro 6 was slated for introduction in 2018, but has been postponed for consideration by the Ministerial Forum on Vehicle Emissions.

Australian emissions and fuel quality standards have generally lagged behind equivalent overseas standards, but they have been progressively tightened to require more sophisticated vehicle engine and emissions control systems, and improved fuel quality. Recent improvements in fuel quality have focused on greatly reducing sulfur content (particularly important in diesel engines, where high sulfur levels prevent the use of catalytic particle filters and NO_x adsorbers) and lowering the volatility of fuels to reduce evaporative losses (a major source of VOCs). The national standard for the sulfur content of diesel fuel has been reduced dramatically from 500 ppm in 2002 to a maximum of 10 ppm since 2009, which meets international best practice. For petrol, the maximum sulfur limit has been 50 ppm for premium unleaded petrol since 2008, and 150 ppm for 'regular' unleaded petrol. The issues associated with reducing the limit in petrol to 10 ppm in line with the current European sulfur limit were canvassed in a 2013 review (Orbital Australia 2013). The *Fuel Quality Standards Act 2000* was reviewed in 2005, and a second extensive review released its final report in April 2016. This review underlined the effectiveness of fuel standards in meeting health, environmental and engine operability objectives.

The Ministerial Forum on Vehicle Emissions was established in October 2015 to bring together the Australian Government infrastructure, environment and energy portfolios to explore options to reduce the environmental and health impacts of vehicle emissions. The forum will coordinate action on a group of issues: implementation of Euro 6 standards, fuel quality standards, fuel efficiency of vehicles and emissions testing.

Domestic wood heater emissions

There are several relevant Australian standards relating to wood heaters, notably AS/NZS 2918 relating to installation, AS/NZS 4012 relating to power and efficiency, and AS/NZS 4013 relating to the rate of particle emissions. The particle emissions standard, which was set at 5.5 grams per kilogram (g/kg) of fuel in 1992 and reduced to 4 g/kg in 1999, was revised in 2014. The new emissions standards are 2.5 g/kg of fuel for heaters sold before 1 September 2019 and 1.5 g/kg for those sold after 1 September 2019. For those with catalytic combustors, the limits are 1.4 and 0.8 g/kg, respectively. All jurisdictions support incorporating the new standards as part of managing emissions from wood heaters.

However, it is recognised that this will not necessarily translate into large reductions in ambient air pollution because of poor compliance with standards by both currently installed and new heaters, and suboptimal in-service use, especially operations causing incomplete combustion and emissions 2–3 times higher than the standard (e.g. NEPC 2013).

Consultation and decision regulation impact statements on reducing emissions from wood heaters have been prepared (NEPC 2013, COAG 2015b). They recommend that states and territories adopt the better practices evident across jurisdictions for stronger compliance and improved in-service measures. Implementation of these measures is slated for 2017 as a priority in the National Clean Air Agreement. Further measures, such as a National Star Rating system or a national audit of industry-based certification procedures, were rejected because of uncertainty about the benefits of such measures.

The NPI estimates that aggregate emissions of PM_{10} from domestic solid fuel burning for 2014–15 were around 20,000 tonnes; this is the same as in 2008–09 because there has been no update to the emissions methodology. This is an underestimate—actual emissions are higher as a result of poor fuel quality or incorrect operation.

On an annual basis, wood smoke in Sydney contributes 19 per cent and 29 per cent of PM_{10} and $PM_{2.5}$ particle pollution, respectively (from both natural and human sources). On a winter weekend day, the contribution of PM_{10} and $PM_{2.5}$ particle pollution from wood smoke can be as high as 48 per cent and 60 per cent, respectively (AECOM 2014). Box ATM11 shows the major contribution of wood smoke to $PM_{2.5}$ levels in Muswellbrook—an average of 62 per cent in winter compared with 0 per cent in summer.

Commercial and other domestic emissions

In major urban centres, air quality can be affected by many small commercial sources, whose small size and large numbers generally make a licence-based approach to control emissions inefficient and impractical. Similarly, numerous domestic sources, such as lawn mowers, leaf blowers and generators, are high polluters relative to their size and levels of use, and add to the overall burden of air pollutants in urban areas. As part of the initial work plan for the NCAA, the environment ministers agreed, in December 2015, to introduce exhaust and evaporative emissions standards for nonroad spark-ignition engines and equipment (COAG 2015a). These standards will be based on international best-practice standards, and will apply to newly manufactured and imported products. Generally, 4-stroke and direct-injection 2-stroke engines would meet the standards, but many conventional 2-stroke engines would not.

Pollution from small commercial sources can lead to loss of local amenity because of odour, dust or noise emissions. Environment protection regulators most often encounter these local problems because of complaints from neighbours. Responses can include regulatory tools, such as abatement notices and compulsory works orders, or requirements to carry out an environmental audit to clarify the source of the problem and identify the most effective solution.

Well-framed land-use planning policies, together with local planning schemes and permits, also play an important part in preventing loss of local amenity due to the impact of odour, dust and noise emissions from industrial and commercial premises. Using planning controls to isolate industrial and commercial operations from residential and other sensitive land uses is not an alternative to requiring such operations to comply with relevant environmental laws. However, planning controls have an important role to play by preventing sensitive uses from locating near incompatible noxious or dangerous facilities, and setting planning permit conditions that complement the requirements of environment protection regulators.

Prescribed burning and bushfires

Prescribed burns, also referred to as planned, controlled or fuel reduction burns, are widely used to reduce the risks of bushfires. Following catastrophic bushfires in several states in the first decade of this century, more prescribed burning is being undertaken, leading to increasing concerns about the impacts of smoke on population health in rural areas, regional towns and major metropolitan areas (Keywood et al. 2015). Even though smoke concentrations are generally lower in major cities, much larger populations can be exposed, so that the overall impact can be high.

States are increasingly using models to predict the dispersal of smoke and identify potentially affected areas. This information is used to help coordinate prescribed burns to minimise the risk of high smoke concentrations within an individual airshed, and even during the process of deciding whether to burn or not.

Nonregulated diesel engines, including shipping and nonroad transport

Nonroad diesel vehicles and equipment—such as bulldozers, loaders and trucks used in construction and industrial activities, and at ports and coalmines—make a significant contribution to human-made particulate and ozone precursor emissions. In the Sydney greater metropolitan region, the nonroad diesel sector is the fourth largest human-made source of $PM_{2.5}$ emissions and the largest unregulated source (see Box ATM15).

New South Wales has taken the lead on managing and reducing nonroad diesel emissions. From 2011 to 2014, the NSW Environment Protection Authority (EPA) ran the Clean Machine Program to raise stakeholder awareness of health impacts of diesel exhaust emissions, and to encourage voluntary emission reductions from nonroad diesel plant and equipment. In 2015, the EPA released the Diesel and Marine Emissions Management Strategy, with the objective of progressively controlling and reducing diesel and marine emissions from priority sectors: shipping, locomotives, and nonroad equipment used by EPA-licensed industry and in government activities. This is also a priority area for the National Clean Air Agreement.

Box ATM15 New policy to reduce emissions from cruise ships

Cruise ship in Sydney Harbour

Photo by K Horrobin, CC BY NC ND 2.0

The cruise ship industry is a strong economic growth area, and Sydney is a popular destination for large ships. Cruise ships berthed in port currently keep their auxiliary engines running to supply the ship with power for air-conditioning, refrigeration and other ship services. The ship exhaust affects the local area, such as around the new White Bay Cruise Terminal in Sydney, and the New South Wales Government has investigated ways to reduce this pollutant.

Typically, ships burn a heavy diesel fuel with a high sulfur content of up to 3.5 per cent, leading to emissions of sulfur dioxide and particulate matter. In the Sydney greater metropolitan region, shipping is responsible for 2.7 per cent of all human-made emissions (NSW EPA 2015). There has been a global push to reduce the sulfur content in shipping diesel, with some countries requiring the use of 0.1 per cent sulfur in their coastal zones, a reduction in sulfur content by a factor of 35. An even cleaner solution when the ship is berthed is the use of shore power, where the ship is plugged in to the city's power distribution network. Many larger ports in North America and Europe require use of shore power, but facilities are yet to be provided in Australian ports.

In 2015, the New South Wales Government introduced regulations limiting the sulfur content of fuel to a maximum of 0.1 per cent for cruise ships at berth in Sydney Harbour from October 2015, and for cruise ships at any time in Sydney Harbour from July 2016. However, these regulations were deemed to be inoperative from 8 January 2016 following amendments to the Commonwealth *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*. With management of marine diesel engine emissions on the National Clean Air Agreement work plan, it is expected that a legislative solution will be found to allow the New South Wales regulations to recommence operation. In the interim, the major cruise ship operators have agreed to comply voluntarily with the low sulfur fuel requirements while at berth.

If all ships used 0.1 per cent sulfur fuel at berth, this could achieve a 25 per cent reduction in $PM_{2.5}$ in suburbs close to Sydney Harbour (Broome et al. 2016). In 20 years time, the human health benefit from adopting a 0.1 per cent sulfur fuel in 2015 in Sydney, Newcastle and Wollongong could result in 390 additional years of life across the population (5.4 million people in 2011). These 390 years are the total time gained by the population as a whole, relating to people who may otherwise have died prematurely because of complications brought on by air pollution.

The improvements to air quality brought about by the low sulfur fuel policy in New South Wales have strong community support. Once a legislated solution is found for them to again be operative, it is planned that they will be extended to New South Wales regional ports, and to other states and territories through the National Clean Air Agreement.

Assessment summary 10
Effectiveness of atmospheric management

Summary	Assessment grade	Confidence	Comparability
	Ineffective / Partially effective / Effective / Very effective	In grade / In trend	To 2011 assessment

Industrial point sources of pollution

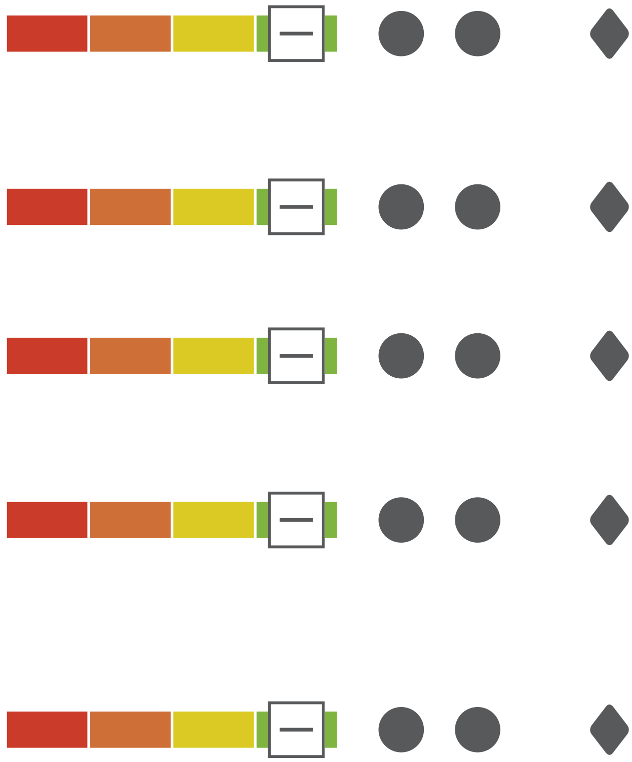
Understanding of context: Generally very good understanding of air pollutants (types, amounts, sources and processes) from relevant industries, and of technologies and practices to prevent or control pollution

Planning: States and territories have well-established plans, policies, legislation and regulatory systems to monitor and control these sources

Inputs: Levels of resourcing to support regulatory and nonregulatory programs vary from jurisdiction to jurisdiction, generally reflecting the nature and extent of industrial sources in the jurisdiction

Processes: All jurisdictions have well-established processes to monitor and control these sources, including reporting, inspection and enforcement processes

Outputs and outcomes: Jurisdictions apply works approvals, licensing and related regulatory mechanisms to limit types and quantities of pollutant emissions. Although performance levels vary, inspection and enforcement by environmental regulators, together with emissions monitoring and reporting, provide a sound basis for ensuring effective control of these sources



Assessment summary 10 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective); Confidence (In grade / In trend); Comparability (To 2011 assessment)
Motor vehicle emissions	
Understanding of context: Good understanding of vehicle tailpipe emissions, and their relation to fuel quality and control technologies. However, differences between test and on-road emissions can be significant. No systematic verification of on-road emissions. Non-tailpipe emissions, such as dust from brake, tyre and road wear, are not as well quantified. Although non-tailpipe emissions are not projected to increase in absolute terms, they are becoming an increasing proportion of total vehicle emissions	
Planning: National and state governments cooperate in relation to planning introduction of improved fuel and engine technology. Introduction of Euro 6, originally proposed for 2018, was postponed. Planning is now through a new Ministerial Forum on Vehicle Emissions, a whole-of-Australian Government approach that includes ministers for environment, infrastructure, transport, major projects, resources and energy	
Inputs: Government cutbacks and focus on deregulation have reduced financial and staffing resources to address management issues. The last national in-service vehicle emissions study was in 2008, leading to considerable uncertainty in emissions factors used in modelling the air quality impact of new motorways and road tunnels, and in urban airshed modelling	
Processes: Well-established national processes for promulgating and enforcing fuel and new vehicle emissions control standards. Improving coordination at the national level between departments with the new Ministerial Forum on Vehicle Emissions. Disbandment of bodies such as the Fuel Standards Consultative Committee has the potential to reduce input from independent experts in decision-making	
Outputs and outcomes: New-vehicle emissions standards (Euro 5) have been introduced since the 2011 state of the environment report. Generally cleaner vehicle fleet has seen a reduction in total tailpipe emissions, despite increases in total distance travelled	

Assessment summary 10 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Domestic wood heater emissions				
Understanding of context: There is a generally good understanding of the particulate emissions from well-operated domestic wood heaters, but incomplete information about real-world emissions and nonparticulate (gaseous) emissions. Strong evidence is available on their significant contribution to poor air quality and related adverse health impacts in many rural towns and urban areas in cooler months. Many factors complicate effective policy action (e.g. socio-economic status, aesthetics, tradition, perceived individual freedom versus community benefit, entrenched attitudes, denial of the problem)	Effective (—)	●	●	X
Planning: National emissions standards for domestic wood heaters were revised in 2015. Some jurisdictions (e.g. NSW) have legislated to allow local government to ban new wood heaters except with specific approval. Plans in National Clean Air Agreement to adopt the best practices across jurisdictions of stronger compliance and improved in-service maintenance by 2017	Partially effective (—)	●	●	X
Inputs: Management is generally the responsibility of local government, which has insufficient financial and human resources to address pollution from each individual heater. Increasing recognition of the need to ban domestic wood heaters (and open fires) in high-density residential areas or in areas with poor dispersion (e.g. valleys) where neighbours are affected	Partially effective (—)	●	●	X
Processes: Emissions standards for domestic wood heaters were updated in 2015, but long life of units means that many operate with higher emissions. Effective management systems are not yet in place, and policies are inconsistent across jurisdictions. Unwillingness of politicians to bite the bullet on this complex and controversial issue	Partially effective (—)	●	●	X
Outputs and outcomes: Poor compliance with standards and suboptimal in-service use reduce the effectiveness of the new standards. Little or no reduction since SoE 2011 in contribution of wood heater emissions to air pollution in many areas during winter	Partially effective (—)	●	●	X

Assessment summary 10 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Commercial and other domestic services				
Understanding of context: Generally good understanding of these pollution types, sources and processes. Most emissions from these sources are estimated using emissions factors rather than measurements because of the large number of sources. However, there is considerable variability and uncertainty in emissions factors for many of these sources				
Planning: State and territory, and (in some jurisdictions) local governments have established plans, policies and regulatory systems to monitor and control these sources. National Clean Air Agreement includes establishing emissions standards for nonroad spark-ignition engines, such as gardening equipment (lawn mowers, brush cutters, leaf blowers, chainsaws, chippers) and recreational boating. Domestic wood heater emissions are considered separately because, overall, they are such a major source of emissions				
Inputs: Resources tend to focus on the significant issues from an airshed or jurisdictional point of view, but are quite variable between jurisdictions. Limited resources and monitoring for localised issues and legacy sources; this is seen by some in the community as leading to inadequate management (e.g. odour complaints)				
Processes: Management systems are in place or being developed (for nonroad spark-ignition engines). Division of responsibilities between jurisdictions and local government is generally clearly defined, but not always clear to the community				
Outputs and outcomes: Generally effective control of emissions, with limited impact on local and (generally) airshed air quality. Complaints about odour and dust continue to be a major air quality issue for local government and environment protection agencies				

Assessment summary 10 (continued)

Summary | Assessment grade (Ineffective, Partially effective, Effective, Very effective) | Confidence (In grade, In trend) | Comparability (To 2011 assessment)

Prescribed burning and bushfires

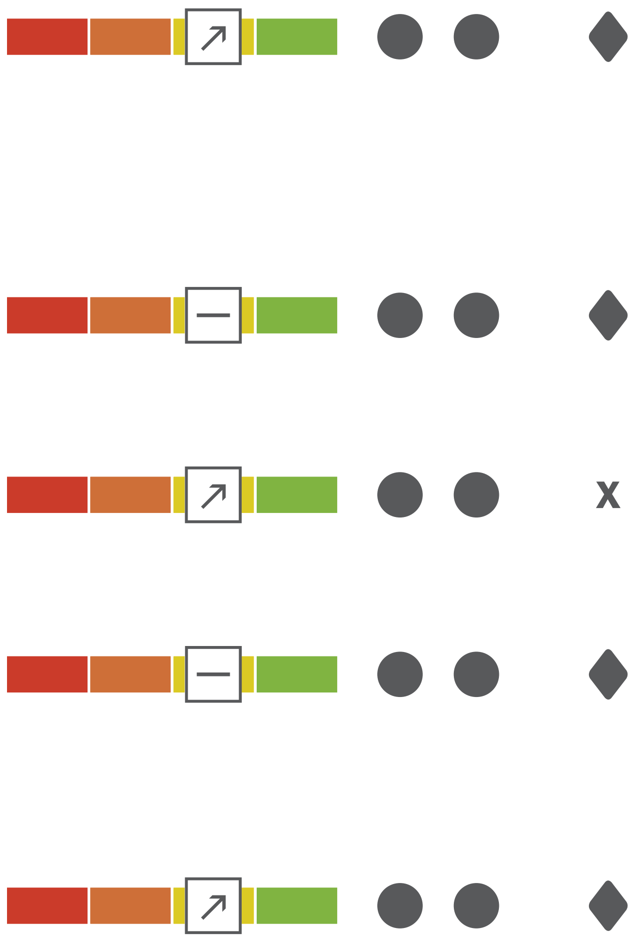
Understanding of context: Good understanding and greater awareness of air quality and health impacts of smoke from prescribed burns and bushfires on firefighters, local communities and more distant communities, which can include large populations in urban areas. Some understanding of the differences in emissions from low-intensity prescribed burns and high-intensity bushfires

Planning: Burning for fuel reduction and habitat management purposes, and for forestry regeneration and related operations is subject to various guidelines or codes of practice, and is usually well planned and executed. Uncertainty about the balance between health impacts and the effectiveness of realistic amounts of prescribed burning for reducing bushfire severity

Inputs: Increasing resources are being directed towards air quality issues in planning burns, especially in improving smoke forecasting models

Processes: In most states and territories, authorities responsible for prescribed burning on public and forestry land have formal arrangements with environment protection agencies, health agencies and local councils, which cover previous notification, suitability of local meteorological conditions, smoke forecasting (sometimes), monitoring and public health warnings

Outputs and outcomes: Improving cooperation between agencies responsible for prescribed burning, and environment and health authorities. Improvements in smoke forecasting capability are being included in planning of operations and giving improved notification to affected populations



Assessment summary 10 (continued)

Summary	Assessment grade (Ineffective / Partially effective / Effective / Very effective)	Confidence: In grade	Confidence: In trend	Comparability: To 2011 assessment
Nonregulated diesel engines, including shipping and nonroad transport				
Understanding of context: Some understanding of emissions from these nonregulated transport sources, mainly large diesel engines, which have proportionately more particulate and NO_x emissions than equivalent petrol engines. They include nonroad vehicles such as earthmoving and mining equipment, locomotives, and vehicles used for commercial shipping and at ports	Effective, Improving	Adequate	Adequate	X
Planning: A national approach to manage these emissions sources is listed for development in the National Clean Air Agreement, following on from the NSW Diesel and Marine Emissions Management Strategy	Partially effective, Improving	Adequate	Adequate	X
Inputs: Resources are currently being deployed to gather information, develop policy proposals and undertake impact assessments	Effective, Stable	Somewhat adequate	Somewhat adequate	X
Processes: Management systems are currently not in place, but are under development in some jurisdictions and listed in the work plan for the National Clean Air Agreement. Lack of consistency and integration of management activities across jurisdictions is a problem	Ineffective, Stable	Limited	Limited	X
Outputs and outcomes: Emissions from new nonroad diesel engines sold in Australia are generally higher than in the United States or European Union. Some engines are poorly maintained and are very smoky. Regulation was introduced in NSW in 2015 to reduce sulfur content of fuel used by cruise ships in Sydney Harbour, but this has since been deemed inoperative because of conflict with Commonwealth legislation. The issue is on the National Clean Air Agreement work plan	Partially effective, Unclear	Limited	Very limited	X

Recent trends

- ↗ Improving
- ↙ Deteriorating
- — Stable
- ? Unclear

Confidence

- **Adequate:** Adequate high-quality evidence **and** high level of consensus
- **Somewhat adequate:** Adequate high-quality evidence **or** high level of consensus
- **Limited:** Limited evidence **or** limited consensus
- **Very limited:** Limited evidence **and** limited consensus
- **Low:** Evidence and consensus too low to make an assessment

Comparability

- **Comparable:** Grade and trend are comparable to the previous assessment
- **Somewhat comparable:** Grade and trend are somewhat comparable to the previous assessment
- **Not comparable:** Grade and trend are not comparable to the previous assessment
- X **Not previously assessed**

Assessment summary 10 (continued)

Management context (understanding of environmental issues; adequacy of regulatory control mechanisms and policy coverage)	
Elements of management effectiveness and assessment criteria	**Grades**
Understanding of context Decision-makers and environmental managers have a good understanding of: • environmental and socio-economic significance of environmental values, including ecosystem functions and cultural importance • current and emerging threats to values. Environmental considerations and information have a significant impact on national policy decisions across the broad range of government responsibilities	**Very effective:** Understanding of environmental and cultural systems, and factors affecting them is good for most management issues **Effective:** Understanding of environmental and cultural systems, and factors affecting them is generally good, but there is some variability across management issues **Partially effective:** Understanding of environmental and cultural systems, and factors affecting them is only fair for most management issues **Ineffective:** Understanding of environmental and cultural systems, and factors affecting them is poor for most management issues
Planning Policies and plans are in place that provide clarity on: • objectives for management actions that address major pressures and risks to environmental values • roles and responsibilities for managing environmental issues • operational procedures, and a framework for integration and consistency of planning and management across sectors and jurisdictions	**Very effective:** Effective legislation, policies and plans are in place for addressing all or most significant issues. Policies and plans clearly establish management objectives and operations targeted at major risks. Responsibility for managing issues is clearly and appropriately allocated **Effective:** Effective legislation, policies and plans are in place, and management responsibilities are allocated appropriately, for addressing many significant issues. Policies and plans clearly establish management objectives and priorities for addressing major risks, but may not specify implementation procedures **Partially effective:** Legislation, policies and planning systems are deficient, and/or there is lack of clarity about who has management responsibility, for a number of significant issues **Ineffective:** Legislation, policies and planning systems have not been developed to address significant issues

Assessment summary 10 (continued)

Management capacity (adequacy of resources, appropriateness of governance arrangements and efficiency of management processes)	
Elements of management effectiveness and assessment criteria	**Grades**
Inputs Resources are available to implement plans and policies, including: • financial resources • human resources • information.	**Very effective:** Financial and staffing resources are largely adequate to address management issues. Biophysical and socio-economic information is available to inform management decisions **Effective:** Financial and staffing resources are mostly adequate to address management issues, but may not be secure. Biophysical and socio-economic information is available to inform decisions, although there may be deficiencies in some areas **Partially effective:** Financial and staffing resources are unable to address management issues in some important areas. Biophysical and socio-economic information is available to inform management decisions, although there are significant deficiencies in some areas **Ineffective:** Financial and staffing resources are unable to address management issues in many areas. Biophysical and socio-economic information to support decisions is deficient in many areas
Processes A governance system is in place that provides for: • appropriate stakeholder engagement in decisions and implementation of management activities • adaptive management for longer-term initiatives • transparency and accountability.	**Very effective:** Well-designed management systems are being implemented for effective delivery of planned management actions, including clear governance arrangements, appropriate stakeholder engagement, active adaptive management and adequate reporting against goals **Effective:** Well-designed management systems are in place, but are not yet being fully implemented **Partially effective:** Management systems provide some guidance, but are not consistently delivering around implementation of management actions, stakeholder engagement, adaptive management or reporting **Ineffective:** Adequate management systems are not in place. Lack of consistency and integration of management activities across jurisdictions is a problem for many issues

Assessment summary 10 (continued)

Achievements (delivery of expected products, services and impacts)	
Elements of management effectiveness and assessment criteria	**Grades**
Outputs Management objectives are being met with regard to: • timely delivery of products and services • reduction of current pressures and emerging risks to environmental values.	**Very effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are being demonstrably reduced **Effective:** Management responses are mostly progressing in accordance with planned programs and are achieving their desired objectives. Targeted threats are understood, and measures are in place to manage them **Partially effective:** Management responses are progressing and showing signs of achieving some objectives. Targeted threats are understood, and measures are being developed to manage them **Ineffective:** Management responses are not progressing in accordance with planned programs (significant delays or incomplete actions) or the actions undertaken are not achieving their objectives. Threats are not actively being addressed
Outcomes Management objectives are being met with regard to improvements to resilience of environmental values.	**Very effective:** Resilience of environmental values is being maintained or improving. Values are considered secured against known threats **Effective:** Resilience of environmental values is improving, but threats remain as significant factors affecting environmental systems **Partially effective:** The expected impacts of management measures on improving resilience of environmental values are yet to be seen. Managed threats remain as significant factors influencing environmental systems **Ineffective:** Resilience of environmental values is still low or continuing to decline. Unmitigated threats remain as significant factors influencing environmental systems

Resilience
of Australia's air quality

At a glance

The frequency, duration and severity of episodes of poor air quality in urban centres are influenced by short-term meteorological conditions, in combination with local topography and/or atypical emissions. Air quality is usually restored to acceptable levels once the immediate conditions change, either through a change in the wind, cessation of the emissions, rain or dispersion of the pollutant. Therefore, our urban airsheds may be considered highly resilient, in terms of the common dictionary definition of the word. However, human resilience to the effects of prolonged or recurring exposure to air pollutants is limited.

Resilience is the environment's capacity to return to a previous state if the system's state has been significantly affected by a disturbance. Australia's metropolitan cities all experience episodes of poor air quality (measured in terms of particulate pollution, or pollution by ozone and its precursors NO_x and VOCs). The frequency, duration and severity of these episodes are strongly influenced by short-term meteorological conditions (principally temperature and wind conditions), in combination with local topography, as well as atypical events such as dust storms, bushfire smoke or accidental releases, such as from factory fires or chemical spills. Air quality is usually restored to acceptable levels once the immediate conditions change, either through a change in the wind, cessation of the emissions or dispersion of the pollutant. In this context, our major urban airsheds are highly resilient.

In addition to the resilience of the atmosphere, it is also important to consider resilience from the perspective of the humans who cause most air pollution and who are affected by it. People have limited resilience in the face of prolonged or recurring exposure to air pollutants (see Health impacts of air pollution). Individuals vary in their sensitivity to exposure to particular air pollutants, with those most sensitive accounting for the great majority of the observed deaths and illness attributed to poor air quality.

Unfortunately, our capacity to adapt to unacceptably high levels of air pollution is inherently limited. We can leave the affected area, shelter indoors (of limited value without effective air filtering), avoid strenuous exercise, wear face masks and, in the case of asthmatics and others with respiratory ailments, take prescribed medicines. However, these strategies are only effective if the pollution is present in a particular area or for a particular time. These short-term adaptive strategies are not substitutes for action to mitigate the pollution at source through a range of regulatory and nonregulatory measures.

Risks
to Australia's air quality

At a glance

During the past 50 years or so since the first clean air Acts were introduced in Australian jurisdictions, state and territory environment protection agencies (often working together with local government) have successfully employed regulatory and nonregulatory measures to greatly reduce threats to urban air quality from industrial, commercial and domestic activities. The risk of this situation changing markedly during the next decade is assessed as low, despite continuing growth of the economy. The lack of effective control measures for smoke pollution from domestic wood heaters needs to be addressed. Although stronger compliance with standards, improved in-service operation and behavioural changes offer some opportunity for cleaner air, the only long-term solution is the same as that for backyard burning, which was banned across urban areas about 30 years ago.

Motor vehicles are the main diffuse source of air pollution in urban areas, and the size of the Australian fleet is continuing to grow, as are the distances travelled. Despite this, projections to 2030 indicate a continued decline in vehicle emissions of most air pollutants. This positive outlook is strengthened by the Australian Government's establishment in 2015 of the Ministerial Forum on Motor Vehicle Emissions to investigate ways to improve the energy productivity of transport, improve air quality and reduce greenhouse gas emissions. Considering these competing factors, the risk of a marked deterioration in urban air quality in the next decade is conservatively assessed as medium.

The higher temperatures associated with climate change are expected to elevate ambient levels of volatile organic compounds, increasing the potential for ozone pollution in Australia's larger metropolitan centres, where peak ozone levels already exceed national air quality standards at times. Climate change is also expected to affect the likelihood of bushfires, which, depending on location, can cause very serious particulate pollution in population centres. The level of risk associated with these outcomes is assessed as medium.

Australian, state, territory and local governments have a range of mechanisms in place to control air pollution at its sources (see Effectiveness of management). In general, these mechanisms have significantly reduced the risk of air pollution events. However, it is worthwhile examining the risks associated with the most likely sources of air pollution in the future: industrial point sources, motor vehicles, domestic wood heaters, commercial and other domestic sources, and climate change. There are also pollutants where more research is required to expand our understanding of their impacts and possible management (see Box ATM16).

Industrial point sources

If not effectively controlled, emissions from industry can place health and amenity at risk, not only at the neighbourhood level, but more generally at the airshed level. During the past 50 years, state and territory environment protection agencies (working together with local government) have successfully employed a range of measures (both regulatory and nonregulatory) to greatly reduce the threat from industrial sources. As a result, apart from in major industrial centres or smaller centres with 1 or 2 significant industrial sources, diffuse sources (commercial and domestic sources, and motor vehicles) tend to be more important threats to urban air quality at an airshed scale.

Motor vehicles

Motor vehicles are a significant source of anthropogenic CO_2 emissions in Australia, comprising some 90 per cent of transport CO_2 emissions, which made up 17 per cent of Australia's net CO_2-equivalent emissions in 2015 (see Sectoral emissions). However, despite their contribution to climate change, the most immediate threat posed by motor vehicles is to air quality. As a proportion of emissions in the NPI, vehicles account for around 40 per cent of emissions of carbon monoxide, 41 per cent of VOCs, 18 per cent of NO_x and 17 per cent of fine particles (as $PM_{2.5}$). It is expected that a more coordinated approach to reduce the health and environmental impacts from motor vehicle emissions will be delivered by the Ministerial Forum on Motor Vehicle Emissions, established in 2015. The forum is investigating ways to improve the energy productivity of transport, improve air quality and reduce greenhouse gas emissions.

From 2011 to 2016, motor vehicle registrations increased by 12.2 per cent (averaging 2.3 per cent annually), which was slightly lower than the 15.4 per cent growth in the previous 5 years. The bulk of this growth was in passenger vehicles, which make up 75 per cent of the total Australian fleet. As noted earlier in this report, despite significant growth in vehicle numbers and distances travelled (which increased by an average 1.9 per cent per year between 2010 and 2014), advances in motor vehicle engine and emissions control technology (together with improved fuel standards) have driven down emissions of carbon monoxide and VOCs. Projections to 2020 show these gains being maintained and levels of NO_x declining. (These projections are based on a 'business as usual' scenario, which does not factor in the progressive application of likely tighter emissions control standards, which should reinforce the projected gains.) However, non-tailpipe particle emissions such as brake and tyre wear are projected to become an increasing proportion of total vehicle emissions in the future.

The threat, however, is that the combination of increasing vehicle numbers, distance travelled and congestion (which leads to more exhaust and evaporative emissions) may cancel out gains in technology, resulting in increased impacts on health and reduced amenity. For example, emerging concerns in Europe about increases in vehicle emissions of NO_2 accompanying technology-driven reductions in NO_x could foreshadow similar concerns in Australia as the proportion of diesel vehicles in the fleet continues to grow. The number of diesel-fuelled registered vehicles grew at 10 per cent per year from 2010 to 2015; at 31 January 2016, they made up 20.9 per cent of all registered vehicles.

Domestic wood heaters

Smoke from domestic wood heaters remains a significant source of air pollution in some urban areas, regional towns and lower-density settlements, often contributing up to 50 per cent of the $PM_{2.5}$ pollution on winter days. It has been identified as a priority in the initial work plan of the NCAA, with the focus on stronger compliance and improved in-service measures by adopting the best practices from across jurisdictions. However, a recent report for the NSW Environment Protection Authority (Databuild 2016) has highlighted the challenge of achieving the required behavioural change. For example, there were important differences in awareness and attitudes among participants in the study in the upper Hunter Valley. The different mindsets around wood smoke were characterised as:

- 'oblivious', who do not understand that wood smoke is harmful to human health
- 'rejecters', who do not accept that wood smoke is harmful to human health
- 'rationalisers', who do not consider any harm caused by wood smoke to be of concern or as bad as that caused by mining (and other industrial sources of particle pollution) in the upper Hunter Valley
- 'conditional accepters', who are prepared to listen and even change their behaviour around wood heaters, as long as they are convinced that it is worthwhile and that any change is not too onerous.

The study indicated that a communication campaign encouraging optimal operation of wood heaters is more likely to be embraced by the community than simply trying to encourage wood heater users to switch to alternative forms of heating. Given the view of some in the upper Hunter Valley community that mines, power stations and associated transport issues are a bigger problem than wood heaters, the study authors noted that messages on wood heaters need to be communicated in the context of other government actions that aim to reduce particle pollution. Otherwise, wood heater users might feel that they are being unreasonably singled out.

Although behavioural changes offer some opportunity for cleaner air, the only long-term solution is the same as that for backyard burning, which was slowly banned across urban areas through the 1980s and 1990s.

Commercial and other domestic sources

Commercial premises can pose a threat to health and amenity at the local level, mainly through emissions of particles and VOCs. VOC sources include aerosols, surface-coating operations and solvents (the latter being a particular cause of odour complaints). Commercial food-processing operations can also place local amenity at risk because of odour emissions. As previously discussed, smoke from poorly designed and operated domestic wood heaters can pose a significant seasonal risk to amenity and health at both neighbourhood and airshed scales. Collectively, domestic and commercial sources annually contribute around one-third of VOCs to the Sydney and Melbourne airsheds, approximately one-quarter to one-third to particulate pollution in Sydney, and one-half to particulate pollution in Melbourne. In the case of Melbourne, the contribution of both VOCs and particles is concentrated in winter, because they are strongly associated with domestic heating.

Climate change

Climate change poses a threat to urban air quality and health through increases in particulate pollution (associated with more frequent bushfires and dust storms), and increases in the formation of ozone and other components of photochemical smog. The latter phenomenon is driven by increasing temperatures, and long-range transport of pollutants associated with large-scale changes in atmospheric circulation.

Box ATM16 Air quality issues identified by jurisdictions as research priorities

At a 2014 symposium to consider future directions for research into air quality in Australia, the Australian Government, and state and territory environment agencies discussed their areas of priority interest and need relating to the management of air quality (Emmerson et al. 2015). Nominated areas included human health impacts, air pollution modelling, and emissions inventories and measurements. There are many 'hot topics' that do not affect all the jurisdictions equally, but are the source of many of the enquiries they receive from the community and other stakeholders. These range from smoke from wood heaters and bushfires (planned and unplanned), to issues surrounding industry and the transport sector.

The key issues identified by the jurisdictions are listed below. Some of these issues were discussed in the 2011 review of the National Environmental Protection Measures (NEPMs; NEPC 2011a), such as the applicability of NEPM air quality standards to air pollution measured at source-affected sites.

Jurisdictional issues

Health issues

- Effect of different types of particles
- Combined impact of multiple pollutants
- Long-term and short-term exposure
- Unique Australian conditions
- Micro-environment exposure

Modelling issues

- Air quality assessments
- Health risk assessments
- Dispersion, chemical and receptor modelling
- Source apportionment techniques
- Secondary particles
- Ozone
- National, regional and local air quality forecasts
- More data for model developments

Box ATM16 (continued)

Measurement issues

- What to measure or monitor?
- Where to measure or monitor? Not just NEPM sites?
- What particulate matter (PM) components to measure—PM_1, ultrafine particles, particle number
- Speciation of particles
- Secondary particles
- Background and continental-scale monitoring, such as the United States Environmental Protection Agency continuous $PM_{2.5}$ and IMPROVE networks
- Measurements to support model development and evaluation
- Intensive campaigns
- Satellite measurements of aerosol optic depth, etc.

Hot topics

- Wood heaters
- Prescribed burns, bushfires
- Industry
- Road tunnels
- Coal trains
- Diesel vehicles
- Local sources
- Climate change and air quality
- Community communication
- Air quality in the planning process
- National air quality database
- Emissions inventories

In addition, the symposium participants raised some key questions:

- What research is needed to optimise the design of monitoring networks to fully represent population exposures (including near-road and near-industry populations) by using a combination of modelling and measurements?
- What research is needed to find the most cost-effective and practical actions to reduce emissions and hence exposure?
- How can the impact of emissions reduction strategies be assessed?
- How can modelling be improved for air pollution incidents (e.g. bushfires, dust storms, industrial accidents)?

Source: Emmerson et al. (2015)


Mount Arawang storm clouds, Canberra
Photo by Helen McFadden

Assessment summary 11

Current and emerging risks to Australia's air quality

	Catastrophic	Major	Moderate	Minor	Insignificant
Almost certain		Premature deaths and respiratory illnesses associated with air pollution, noting that outdoor air pollution, including particulate matter, has been classified by the World Health Organization as carcinogenic to humans			
Likely			Adverse health effects, including respiratory illnesses and loss of amenity due to short-term exposure to wood smoke from domestic wood heaters, hazard reduction burns and bushfires Localised impacts on health and amenity due to air pollution from industry Climate change increasing particulate pollution (associated with more frequent bushfires and dust storms) and formation of photochemical smog		
Possible			National Clean Air Agreement ineffectual, leading to steady or increasing exposure to pollutants		
Unlikely		No increase in provision and use of public transport, with the potential to significantly worsen urban air quality Abandonment of environmental controls on development Major economic recession			
Rare	Not considered	Not considered	Not considered	Not considered	Not considered

Not considered

Outlook
for Australia's air quality

At a glance

The outlook for Australia's urban air quality is generally good. However, there is strong evidence that periods of poor urban air quality can have serious adverse long-term and short-term impacts on human health (particularly on the health of susceptible individuals). Although levels of carbon monoxide, lead, nitrogen dioxide and sulfur dioxide have decreased in the past 10 years, ozone and particle levels have not declined, and ongoing effort will be required to secure past gains and achieve further improvements. Prospects for achieving reductions in levels of ozone and particles will be influenced by several factors, most notably vehicle technology, the extent of ongoing population growth and urban sprawl, the availability of reliable public transport, and the impact of climate change on urban airsheds.

Air quality in Australia's urban centres is generally good to very good. Levels of carbon monoxide, lead, nitrogen dioxide and sulfur dioxide are generally well below the Air NEPM standards, and continue to decrease in most locations. An exception is Mount Isa and Port Pirie, where the 1-hour standard for sulfur dioxide is still exceeded on more than 20 days each year because of emissions from ore smelting facilities. The situation in Port Pirie is expected to improve dramatically from 2017 when the smelter transformation project is completed, which will reduce average sulfur dioxide emissions by a factor of almost 10.

In contrast, maximum ozone and PM levels have not declined in Australia's urban areas. The 4-hour ozone standard is typically exceeded a few times per year in Sydney, and occasionally in Melbourne and Perth. The PM_{10} goal of not more than 5 exceedances of the 24-hour standard is generally met in capital cities, but less often in regional and rural towns. The 2016 revision of the Air NEPM, which replaced the allowance of 5 exceedances by an exceptional event rule, might lead to a sharper focus on sources that can be controlled.

For fine particulate matter, $PM_{2.5}$, the standard does not allow any exceedance, and most capital cities exceed the 24-hour standard at some time during the year. The best performing cities are Brisbane and Adelaide, which met the standard for 5 and 4, respectively, of the 7 years to 2014.

National health-based standards are rarely exceeded for prolonged periods, and very high levels of pollution are usually associated with short-lived extreme events such as bushfires and dust storms, or local sources of pollutants.

Despite the generally good to very good quality of Australia's air, strong evidence shows that periods of poor air quality can have both long-term and short-term adverse impacts on human health. Research into the health effects of particulates, ozone and sulfur dioxide indicates that there is no threshold level below which they have no health effect. This means that sensitive individuals, such as asthmatics and people with respiratory or cardiovascular disease, may be affected even when air quality standards are met. This—and the classification by the World Health Organization in 2013 of outdoor air pollution and one of its major constituents, PM, as carcinogenic—has strengthened the case for decisive action to improve air quality.

Emissions of air pollutants from major industrial point sources are generally well controlled in all Australian jurisdictions, although some regional cities still record exceedances of national standards because of industrial emissions. The effect of these sources on urban air quality is expected to slowly diminish with the continued uptake of cleaner technologies.

Similarly, no evidence exists to suggest that urban air quality will decline because of an increase in emissions from diffuse commercial sources. As is the case with industrial sources, continuing uptake of improved practices and technologies (driven by a desire for improved efficiency, as well as by the prompting of regulators) may see a reduction in emissions of some pollutants, such as VOCs.

Air pollution from domestic sources (largely particulate pollution from wood smoke) can be expected to continue to reduce air quality in neighbourhoods where wood heaters are still widely used. It is unlikely that behavioural change will lead to a significant reduction in emissions, but the increasing cost of purchasing wood in metropolitan areas might. Our limited capacity to control many sources of PM is likely to exert increasing pressure for further restrictions or bans on the use of domestic wood heaters in urban areas.

Motor vehicles are the main diffuse source of air pollution in urban areas, and the size of the Australian fleet is continuing to grow, as are the distances travelled. In addition, there is concern about the impact on air quality of growing traffic congestion and continuing urban sprawl. Based on a 'business as usual' scenario (which does not include further tightening of emissions standards), projections to 2020 indicate a continued decline in vehicle emissions of the main air pollutants (carbon monoxide, NO_x, PM and VOCs), but total vehicle emissions of particulates have plateaued. Further reductions in PM present a major challenge because the non-exhaust contribution (brake, tyre and road wear) is becoming a larger proportion of the total.

There are reasonable grounds for optimism that reductions achieved in some urban air pollutants (carbon monoxide, lead, NO_2, sulfur dioxide) during the past decade can be maintained or even extended. Prospects for achieving significant reductions in average and peak levels of particulates and ozone will be influenced by:

- the rate at which pollutant emissions per person decrease to balance the projected doubling of population in the next 50 years
- the rate at which vehicles (particularly passenger vehicles) shift to hybrid, electric or other forms of low-emissions or no-emissions propulsion
- improvements in public transport
- increased take-up of cleaner forms of production
- reductions in the use of wood as a fuel for domestic heating in both urban and semi-rural settings.

Acronyms and abbreviations

Acronym or abbreviation	Definition
ADR	Australian Design Rule
Air NEPM	National Environment Protection Measure for Ambient Air Quality
AQI	air quality index
AR5	Fifth Assessment Report (IPCC)
CFC	chlorofluorocarbon
CO_2	carbon dioxide
ENSO	El Niño–Southern Oscillation
ERF	Emissions Reduction Fund
GDP	gross domestic product
GHG	greenhouse gas
GWh	gigawatt hour
HFC	hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
LULUCF	land use, land-use change and forestry
$MtCO_2$-e	megatonne of carbon dioxide equivalent
$\mu g/m^3$	micrograms per cubic metre
NCAA	National Clean Air Agreement
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NEPP	National Energy Productivity Plan
NO_x	generic term for the nitrogen oxides (NO and NO_2)
NO_2	nitrogen dioxide
NPI	National Pollutant Inventory

Acronym or abbreviation	Definition
OECD	Organisation for Economic Co-operation and Development
PFC	perfluorocarbon
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 microns in size
PM_{10}	particulate matter less than 10 microns in size
ppb	parts per billion
ppm	parts per million
RCP	Representative Concentration Pathway
RET	Renewable Energy Target
SF_6	sulfur hexafluoride
SoE	state of the environment
VOC	volatile organic compound

Glossary

Term	Definition
airshed	A region where topography and meteorology limit the movement of air pollutants from the area.
air toxics	A group of pollutants found in ambient air, usually at relatively low concentrations, including heavy metals and many types of volatile and semivolatile organic compounds. These include known or suspected carcinogens and pollutants linked to other serious health impacts, including birth defects, and developmental, respiratory and immune system problems.
ambient air	Outdoor air.
anthropogenic	Caused by human factors or actions.
carbon dioxide equivalent (CO_2-e)	A measure that combines the global warming effect of the 6 greenhouse gases listed in Annex A of the Kyoto Protocol—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6)—into a single meaningful number. Specifically, CO_2-e represents the carbon dioxide emissions that would cause the same heating of the atmosphere as a particular mass of an Annex A greenhouse gas.
carbon sequestration	Processes to remove carbon from the atmosphere, involving capturing and storing carbon in vegetation, soil, oceans or another storage facility.
climate change	A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and is additional to natural climate variability observed over comparable time periods (under the terms of the United Nations Framework Convention on Climate Change).
condition	The ‘health’ of a species or community, which includes factors such as the level of disturbance from a natural state, population size, genetic diversity, and interaction with invasive species and diseases.

Term	Definition
decline	When the condition of an ecosystem, species or community has decreased to a point where its long-term viability is in question. It usually represents more than just a decrease in numbers of individuals, and describes the result of several interacting factors (e.g. decreasing numbers, decreasing quality or extent of habitat, increasing pressures). In this report, the use of the term is generally prompted by reports that a substantial number of species within a group or community are classified as threatened and there is a high likelihood that more species are likely to qualify for a threatened classification if trends continue. Where 'decline' is applied to elements of environments (e.g. condition of vegetation as habitat), it means that changes have been sufficient to potentially affect the viability of species relying on those elements.
disturbance	A temporary change in average environmental conditions that disrupts an ecosystem, community or population, causing short-term or long-term effects. Disturbances include naturally occurring events such as fires and floods, as well as anthropogenic disturbances such as land clearing and the introduction of invasive species.
drivers	Overarching causes that can drive change in the environment; this report identifies climate change, population growth and economic growth as the main drivers of environmental change.
ecological processes	The interrelationships among organisms, their environment(s) and each other; the ways in which organisms interact, and the processes that determine the cycling of energy and nutrients through natural systems.
ecology	*See* ecological processes.
ecosystem	An interrelated biological system comprising living organisms in a particular area, together with physical components of the environment such as air, water and sunlight.
ecosystem services	Actions or attributes of the environment that are of benefit to humans, including regulation of the atmosphere, maintenance of soil fertility, food production, regulation of water flows, filtration of water, pest control and waste disposal. It also includes social and cultural services, such as the opportunity for people to experience nature.
El Niño	A periodic extensive warming of the central and eastern Pacific Ocean that leads to a major shift in weather patterns across the Pacific. In Australia (particularly eastern Australia), El Niño events are associated with an increased probability of drier conditions. *See also* La Niña.
emissions	Output or discharge, as in the introduction of chemicals or particles into the atmosphere.
emissions trading	A system of market-based economic incentives to reduce the emission of pollutants.
general resilience	Resilience to unknown or unidentified pressures, disturbances or shocks.
global warming	*See* greenhouse effect.

Term	Definition
greenhouse effect	Where thermal energy (infrared radiation) that otherwise would have been radiated into space is partially intercepted and reradiated (some of it downwards) by atmospheric greenhouse gases, resulting in warmer temperatures at the planet's surface. The greenhouse effect has supported the development of life on Earth; however, strengthening of the greenhouse effect through human activities is leading to climate change (also known as global warming).
greenhouse gases	Gases that contribute to the greenhouse effect, the most important of which are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), short-lived tropospheric ozone (O_3), water vapour, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).
gross domestic product	The total market value of goods and services produced in a country in a given period, after deducting the cost of goods and services used in production but before deducting allowances for the consumption of fixed capital.
jurisdiction	An Australian state or territory, or under the control of the Australian Government.
Kyoto Protocol	An international agreement that commits industrialised nations to stabilising the level of greenhouse gas emissions; the agreement is linked to the United Nations Framework Convention on Climate Change.
La Niña	A periodic extensive cooling of the central and eastern Pacific Ocean. In Australia (particularly eastern Australia), La Niña events are associated with an increased probability of wetter conditions. *See also* El Niño.
millennium drought	The recent drought in southern Australian that lasted from 2000 to 2010 (although in some areas it began as early as 1997).
mitigation	Actions intended to reduce the likelihood of change or the impacts of change.
Montreal Protocol	The Montreal Protocol on Substances that Deplete the Ozone Layer aims to reduce or eliminate human use of substances that deplete the atmospheric ozone layer.
NO_x	A generic term for nitric oxide and nitrogen dioxide.
ozone depleting substances	Substances that break down stratospheric ozone, principally chlorofluorocarbons, freons and halons, used as refrigerants, industrial solvents and propellants in aerosol spray cans. These substances are stable and long-lived in the lower atmosphere, but drift up to the stratosphere where they break down through the action of ultraviolet radiation. This releases highly reactive atoms (chlorine and bromine) that react with ozone molecules and break them apart. *See also* stratospheric ozone.
ozone layer	*See* stratospheric ozone.
pathogen	A microorganism that causes harm to its living host.
peri-urban	A region between the outer suburbs and the countryside.
pressures	Events, conditions or processes that result in degradation of the environment.

Term	Definition
radiative forcing	A measure of the influence a factor (such as greenhouse gases) has on altering the balance of incoming and outgoing energy in the Earth–atmosphere system. Warming of climate is a response to positive radiative forcing, while cooling is a response to negative radiative forcing.
resilience	Capacity of a system to experience shocks while retaining essentially the same function, structure and feedbacks, and therefore identity.
smog	Fog mixed with smoke (i.e. mixing of particulate pollutants with water droplets). Photochemical smog results from the action of sunlight on nitrogen oxides and hydrocarbons present in a polluted atmosphere.
specific resilience	Resilience to identified pressures, disturbances or shocks.
stratosphere	A layer of Earth's atmosphere, beginning at an altitude of around 10 kilometres above Earth's surface and extending to approximately 50 kilometres.
stratospheric ozone	A layer of ozone in the stratosphere that limits the amount of harmful ultraviolet light passing through to lower layers of the atmosphere.
sustainability, sustainable	Using 'natural resources within their capacity to sustain natural processes while maintaining the life-support systems of nature and ensuring that the benefit of the use to the present generation does not diminish the potential to meet the needs and aspirations of future generations' (*Environment Protection and Biodiversity Conservation Act 1999*, p. 815). 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (United Nations Brundtland Commission).
threshold	A boundary between 2 relatively stable states; a point where a system can go rapidly into another state, usually because of positive feedback(s).
troposphere	The lowest layer of Earth's atmosphere. Its depth varies with latitude, averaging around 17 kilometres in the mid-latitudes.
volatile organic compounds (VOCs)	A group of carbon-based chemicals that easily evaporate at room temperature. Common VOCs include acetone, benzene, formaldehyde, methylene chloride, toluene and xylene. Different VOCs have different health effects, ranging from those that are highly toxic to those with no known health effect. Some react with oxides of nitrogen in photochemical processes to generate a range of secondary pollutants (notably ozone).
wildfire	An unplanned fire, whether accidentally or deliberately lit (in contrast to a planned or managed fire lit for specific purposes, such as fuel reduction).

Acknowledgements

The authors would like to thank everyone who has contributed to this report.

Kylie Kulper from the Department of the Environment and Energy SoE team worked tirelessly keeping us on track, and chasing data, images and licences. In the later stages, Lucy Tunks took on that role.

Lynette Bettio, Karl Braganza and Alex Evans from the Bureau of Meteorology contributed to 'State and trends of Australia's climate'.

Paul Krummel, Paul Fraser and Nada Derek from CSIRO Oceans and Atmosphere contributed to 'Pressures affecting Australia's climate'.

Tamara Curll, Brooke Perkins, Glenn Whitehead, Chris Golding, Aaron Kirby and Katie Eberle from the department's Domestic Emissions Reduction Division and International Climate Change and Energy Innovation Division contributed to 'Pressures affecting Australia's climate', and provided valuable comments on drafts.

Angela Yeomans, Declan O'Connor Cox, Pat McInerney, Edward Ho-Shon, Angela Jones and Eszter Szabo from the department's Environment Standards Division, and Kevin Hennessey and Michael Grose from CSIRO Oceans and Atmosphere provided valuable comments on drafts.

Fabienne Reisen, Sarah Lawson, Ian Galbally, Suzie Molloy, Tony Hirst, Arnold Sullivan and Mick Meyer from CSIRO Oceans and Atmosphere; Jeremy Russel-Smith from Charles Darwin University; and Stephen Wilson from the University of Wollongong contributed information for case studies.

We thank the following for providing air quality data for 'State and trends': John Frame (Victoria), Alan Betts (New South Wales), David Wainwright (Queensland), Tina Runnion (Western Australia), Pushan Shah (South Australia), John Innes (Tasmania), Michael Bruvel (Northern Territory) and David Power (Australian Capital Territory).

Thanks also to Ann-Louise Crotty for advice on the New South Wales shipping emissions policy, and Nick Agapides for assistance in drawing Figure ATM30.

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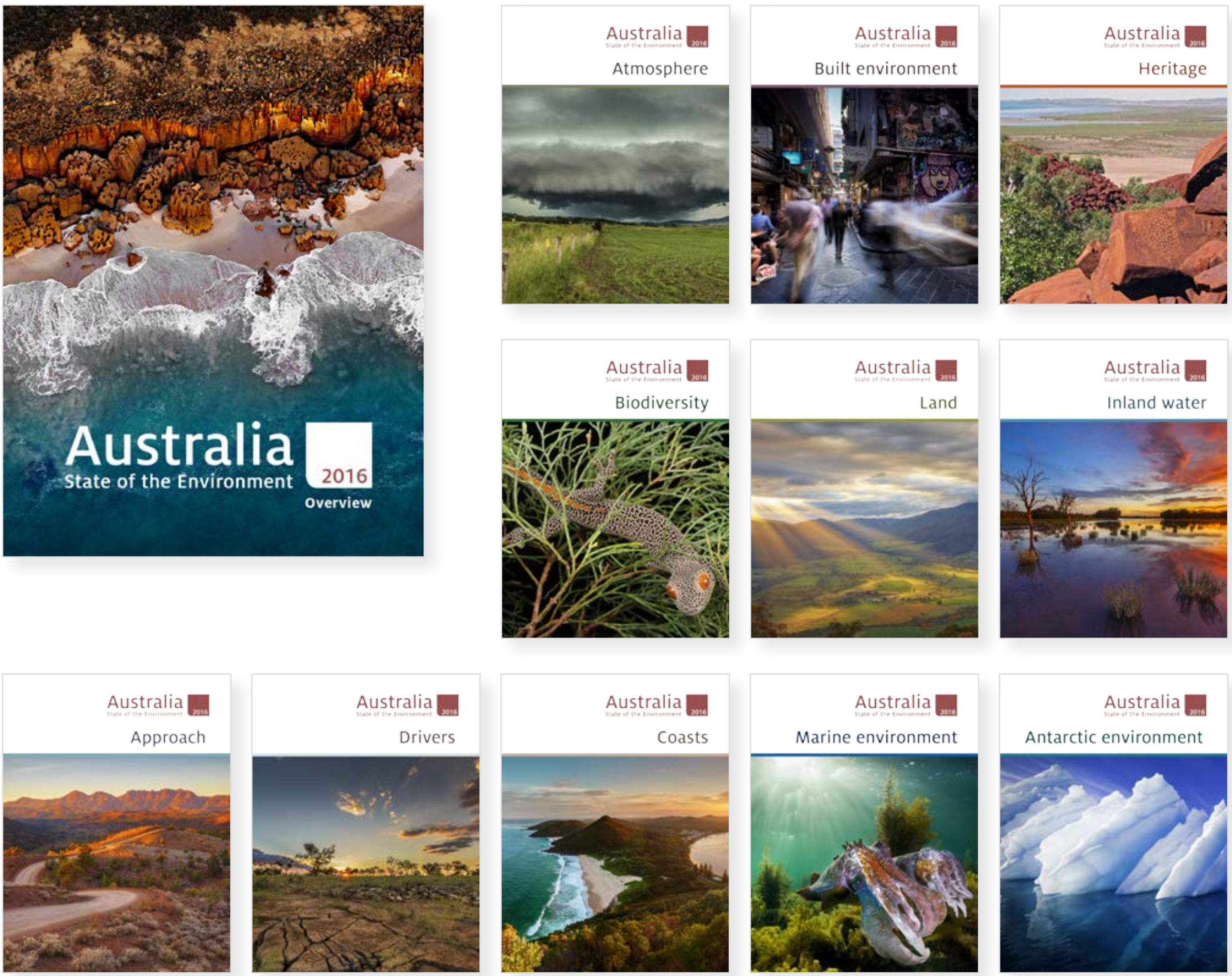

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