2

Global heating

Introduction

2.1 This chapter examines the scientific evidence for global heating and its causes, and discusses the predicted effects on Australia's climate, including changes to temperature, rainfall, sea levels and ocean acidification.

2.2 Heating of the global climate system has already affected and will continue to have effects across the country into the future, including potentially serious effects upon iconic areas such as the Great Barrier Reef. The chapter considers what level of carbon in the atmosphere is necessary to avoid serious climate disruption.

2.3 Participants in the inquiry frequently referred to the scientific assessments of the International Panel on Climate Change (IPCC) and particularly its 2007 Fourth Assessment Report as a primary source for understanding global heating.[1]

2.4 For emissions scenarios, participants largely used the main emission scenarios described in the IPCC Special Report on Emissions Scenarios

1 The IPCC is a scientific governmental body set up by the World Meteorological Organization and the United Nations Environment Program and is contributed to by scientists from all over the world (www.ipcc.ch/about/index.html).

(SRES)[2] as a starting point for their analysis. The Committee has also relied upon the IPCC's scientific data for global climate change.

The evidence for global heating

2.5 Evidence obtained from ice cores has demonstrated that over the last 400,000 years, global temperatures have varied in alignment with glacial and interglacial periods. Carbon dioxide concentrations in the atmosphere over this period have ranged from 180 parts per million[3] to around 280 parts per million, cycling in parallel with temperature changes.[4]

2.6 In the last 150 years, the long term trend has been an increase in global temperatures, both on the surface of the planet and in the oceans, and an increase in carbon dioxide (CO_2) concentrations in the atmosphere to currently around 380 parts per million (ppmv).[5]

2.7 The CSIRO has explained the change in carbon dioxide concentrations as follows:

> The natural sources and sinks for CO_2 have varied widely during past glacial and interglacial cycles but have remained below 300ppmv for at least 420,000 years. With the industrial revolution, humans began transferring carbon that was effectively locked away in the Earth's crust to the atmosphere, upsetting the balance of the carbon cycle. The nature sinks for carbon (primarily terrestrial vegetation and oceans) currently sequester ~40% of emissions from fossil fuel sources. The remaining 60% remains in the atmosphere. As a result, atmospheric CO_2 concentrations have increased from 280ppmv at the start of the industrial revolution to their current concentration of over 370ppmv. The current rate of atmospheric CO_2 accumulation (~1.8 ppmv/year) is approximately 2-3 times that of the early 1960s.[6]

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2 More information on these scenarios can be found at http://www.ipcc.ch/ipccreports/sres/emission/index.htm. See also Intergovernmental Panel on Climate Change (IPCC), *Climate change 2007: Synthesis report*, 2008, p. 44.

3 Parts per million is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air. For example, 300 parts per million means 300 molecules of greenhouse gas per million molecules of dry air.

4 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 2.

5 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 2.

6 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, p. 11, *Exhibit No. 7.*

2.8 In its Fourth Assessment Report, the IPCC stated that warming of the global climate system is 'unequivocal' as demonstrated by increasing global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.[7]

2.9 The IPCC has presented the following evidence for global heating:

- Eleven of the years in the twelve year period of 1995-2006 ranked amongst the warmest years in the instrumental record of global surface temperature (that is, since 1850).
- The 100 year linear trend in the global average surface temperature to 2005 showed an increase of 0.74 degrees Celsius. Global average surface temperature has particularly increased since about 1950.
- Observations since 1961 have shown that the average temperature of the global ocean to a depth of at least 3000 metres has increased and that the ocean has been taking up over 80 percent of the heat being added to the climate system. Such warming causes seawater to expand, contributing to sea level rise.
- Global sea levels rose at an average rate of 1.8mm per year from 1961 to 2003 and at an average rate of about 3.1mm per year from 1993 to 2003.
- Snow and ice extent have decreased. Satellite data since 1978 showed that the annual average Arctic sea ice extent has shrunk by 2.7 percent per decade. Mountain glaciers and snow cover on average have declined across the globe.
- Long term changes in rainfall have been observed since 1900 in many regions with both significant increases and decreases.
- Some extreme weather events have changed in frequency and/or intensity over the last 50 years.[8]

7 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 30.

8 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 30. See also Solomon, S. et. al, 2007, Technical Summary, in *Climate change 2007: The physical science basi*s, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, (referred to hereafter as the IPCC Technical Summary) for detailed discussion of this evidence.

The evidence that global heating is the result of human activity

2.10 Analysis of the global heating observed since the mid nineteenth century has identified increased concentrations of greenhouse gases and aerosols as the cause.[9] The IPCC considers that there is a greater than 90 percent probability that most of the warming since the mid twentieth century has been caused by the rapid increase in greenhouse gas concentrations resulting from human activities since the industrial revolution.[10]

2.11 Changes in atmospheric concentrations of greenhouse gases and aerosols, land cover and solar radiation alter the energy balance of the climate system by affecting the absorption, scattering and emission of radiation within the atmosphere and at the Earth’s surface. The resulting positive or negative changes in energy balance are expressed as radiative forcing. This is then used to compare warming or cooling influences on the global climate.[11]

2.12 It is generally accepted that the warming effect is largely brought about by carbon dioxide, methane and, to a lesser extent, ozone, (collectively part of the family of greenhouse gases). The counteracting cooling influences result from aerosols: particulate matter put into the atmosphere largely as a result of pollution from industrialisation. The warming influences have been found to greatly outweigh the cooling and are considered to be almost entirely attributable to human influence.[12]

2.13 The IPCC has stated that human activities are responsible for emissions of four long-lived greenhouse gases: carbon dioxide, methane, nitrous oxide and halocarbons. These gases are chemically stable and persist in the atmosphere for up to centuries or longer. Emission of these gases therefore has a long term influence on climate.[13] Where emissions are greater than the absorption by sinks, the gases are concentrated in the atmosphere.

2.14 The IPCC assessed that global atmospheric concentrations of carbon dioxide, methane and nitrous oxide:

> …have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice

9 The term ‘aerosol’ refers to tiny particles suspended in the atmosphere.

10 IPCC, *Climate change 2007: Synthesis report,* 2008, pp. 30, 37.

11 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 37.

12 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 2; IPCC, *Climate change 2007: Synthesis report,* 2008, p. 39.

13 IPCC Technical Summary, p. 24.

> cores spanning many thousands of years … The atmospheric concentrations of CO_2 [carbon dioxide] and CH_4 [methane] in 2005 exceed by far the natural range over the last 650,000 years.[14]

2.15 Global greenhouse gas emissions increased by 70 percent between 1970 and 2004.[15] The IPCC divided these emissions into the following groups:

- carbon dioxide, fossil fuel use: 56.6 percent;
- carbon dioxide, deforestation, decay of biomass: 17.3 percent;
- carbon dioxide, other: 2.8 percent;
- methane: 14.3 percent;
- nitrous oxide: 7.9 percent; and
- f-gases (hydrofluorocarbons, perfluorocarbons and sulphurhexafluoride): 1.1 percent.[16]

2.16 Carbon dioxide is considered to be the most important human caused greenhouse gas, with its annual emissions growing between 1970 and 2004 by about 80 percent from 21 to 38 gigatonnes. As shown in the data above, carbon dioxide represented 77 percent of total human caused greenhouse gas emissions in 2004.[17]

2.17 The global atmospheric concentration of carbon dioxide increased from a preindustrial value of about 280 parts per million to 379 parts per million in 2005. Similarly, methane increased from 715 parts per billion to 1774 parts per billion and nitrous oxide increased from 270 parts per billion to 319 parts per billion.[18]

2.18 As noted earlier, these changes in the composition of the atmosphere alter the radiative balance of the Earth, that is, the balance between incoming solar radiation and outgoing heat. Greenhouse gases reduce the radiation of heat from the Earth's atmosphere into space, trapping more heat in the atmosphere and thus increasing global temperatures.[19]

2.19 The IPPC attribute the largest growth in greenhouse gas emissions between 1970 and 2004 to energy supply, transport and industry. Residential and commercial buildings, forestry (including deforestation)

14 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 37.

15 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 36.

16 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 36.

17 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 36.

18 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 37.

19 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 6-7, *Exhibit No. 7.*

and agricultural sectors have also grown, but at a slower rate.[20] Global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use changes. Increases in methane and nitrous oxide are primarily due to agriculture.[21]

2.20 Studies have shown that solar radiation, a natural form of warming, has had a very small impact on temperature compared with human influences.[22]

Observed effects of global heating

2.21 Based upon studies since 1970, the IPCC concluded in 2007, with either very high (greater than 90 percent) or high (greater than 80 percent) confidence, that global heating has had discernable impacts on physical and biological systems.[23] This includes:

- natural systems related to snow, ice and frozen ground (eg, glacial lakes, permafrost regions and Arctic and Antarctic ecosystems);
- hydrological systems (eg, runoff and discharge in glacier and snow fed lakes, and warming of lakes and rivers);
- terrestrial biological systems (eg, the early onset of spring events); and
- marine and freshwater biological systems (eg, range and abundance of species) associated with rising water temperatures and changes in ice cover, salinity, oxygen levels and circulation.[24]

2.22 While the IPCC concluded that warming had also impacted upon managed and human systems, such as agricultural and forestry management and human health, these impacts were more difficult to distinguish because of adaptation and other non-climatic drivers.[25]

2.23 For Australia, the effects of global heating can be seen through changes to temperature, rainfall, sea levels and ocean acidification. However, the

20 IPCC, *Climate change 2007: Synthesis report*, 2008, p. 36.

21 IPCC, 2007, Summary for Policymakers, in *Climate change 2007: The physical science basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 2.

22 Dr Andrew Ash, *Transcript of Evidence*, 1 December 2008, p. 2.

23 IPCC, *Climate change 2007: Synthesis report*, 2008, p. 31.

24 IPCC, *Climate change 2007: Synthesis report*, 2008, pp. 31, 33.

25 IPCC, *Climate change 2007: Synthesis report*, 2008, p. 33.

observed effects of heating differ across the country. Australia's climate is highly variable, particularly in the context of rainfall, which is cyclical and influenced by factors such as El Nino and La Nina. The southern parts of Australia are dominated by a Mediterranean climate with winter rainfall, while northern Australia experiences monsoonal influences and summer dominant rain.[26]

Temperature, rainfall, run off and drought

2.24 The long-term trend for Australia has been an increase in temperature of about 0.9 degrees Celsius over the last 100 years or so.[27] Air temperature increases have been accompanied by marked declines in regional rainfall, particularly along the east and west coasts of the continent.[28]

2.25 Warming has been associated with an increase in the frequency of hot days, hot nights and heatwaves, and a decreased frequency of cold days and cold nights, increases in heavy rain events, and decreases in spring-time snow depth in the Snowy Mountains.[29]

2.26 Temperature increases have occurred not only at the surface of the planet but also in the oceans. Substantial warming has occurred in the three oceans surrounding Australia, but most particularly off the south-east coast and in the Indian Ocean.[30]

2.27 The CSIRO provided evidence on annual rainfall trends for the period 1950 to 2007, which illustrated a strong drying trend in south-west Western Australia and a quite strong drying trend through eastern Australia. According to Dr Ash of the CSIRO, the causes of these drying trends are much more complex than the temperature increases:

> The drying trend in south-west Western Australia and, to a smaller extent, in south-eastern Australia we believe is attributable to climate change and the way that the frontal systems that go across southern Australia in winter, which bring a fair bit of the rain, have moved southwards as a result of a change in pressure systems from Antarctica up to the middle latitudes.

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26 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 4.

27 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 2.

28 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 2.

29 Jones D.A., Watkins, A.B. and Hennessy, K., *Humans do contribute to global heating,* Engineers Australia, September 2005, pp. 44-47, www.csiro.au/resources/pfxh.html, viewed on 2 February 2009.

30 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections*, 2007, p. 3.

> We are confident that some of the rainfall decreases that we are observing in southern Australia are at least in part attributable to greenhouse gas emissions.[31]

2.28 In the same period, rainfall increased in north-western and central Australia and over the western tablelands of New South Wales.[32]

2.29 The CSIRO indicated that a significant contributor to rainfall increases observed in northern and north-western Australia over the last 30 to 40 years is increased aerosols over Asia as a result of industrialisation.[33]

2.30 Small changes in rainfall can lead to significant declines in runoff into storage areas and dams. Dr Ash told the Committee that a one percent decrease in rainfall can lead to a three to four percent decrease in runoff. A five percent decrease in rainfall can lead to quite significant declines in run off into storage areas and dams. [34] For example, in relation to the Murray-Darling Basin, run off is not occurring as the ground is very dry as a result of the current drought and any rainfall is taken up by the ground. The combination of very low rainfalls and higher temperatures is drying out the whole system and without run off dam levels and water levels are at historic lows.[35]

2.31 In its submission, the Murray Darling Basin Commission highlighted that while average annual inflows to the River Murray system are 11,100 gigalitres[36], inflows to the River Murray system in 2006-07 were approximately 1,000 gigalitres – nine percent of average annual inflows.[37]

2.32 With increasing temperatures, the effects of drought are exacerbated because as it gets hotter plants use more water. As a result, even with the same amount of water in the system, 'you are getting the impact of the drought through increased temperatures'.[38]

2.33 While a lot of the droughts currently being observed are still largely within the bounds of historical natural cycling in terms of rainfall, such as that for the Murray-Darling Basin, the CSIRO considers that they have been

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31 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 3.

32 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections*, 2007, p. 2.

33 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 9.

34 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 4.

35 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 6.

36 Estimated over the period 1891 to 2007.

37 Murray Darling Basin Commission, *Submission No. 26,* p. 1.

38 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 5.

exacerbated significantly by the higher temperatures over the last hundred years; that is, by global heating.[39]

Sea levels

2.34 Over a period of thousands of years, there have been large changes in sea level as the Earth's climate has cycled between glacial and inter-glacial periods. These sea level changes were driven predominantly by melting and freezing of ice on land.[40]

2.35 From about 1,000 years ago to the late nineteenth century, sea level was relatively stable, with a variation of less than about 0.2 metres over the whole period. This compares with changes of up to four metres in the period from 21,000 to 2,000 years ago.[41]

2.36 However, in the twentieth century sea level again rose significantly and, according to the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), at a rate that has not been experienced in the past 5,000 years:[42]

> While sea level has varied by more than 120m during ice age cycles, there was little net change in global average sea level from 0 AD to about 1800 AD – the time during which most of the world's coastal development has occurred. Over the last 130 years, the rate of sea-level rise has increased and since the launch of satellites to measure sea-levels in the early 1990s, it is over 3mm/year. This rate is unprecedented in the 20th century.[43]

2.37 The global average rise for the twentieth century is 0.17 metres.[44] Unlike the sea level changes associated with earlier glacial and interglacial cycles, recent sea-level rise is increasingly the result of a warming ocean and the corresponding thermal expansion.[45]

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39 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 6.

40 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A,* p. 4.

41 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A,* p. 5.

42 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A,* p. 5.

43 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment B,* p. 3.

44 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A,* p. 5.

45 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A,* p. 6.

2.38 The ACE CRC also notes that observed sea level is currently tracking near the upper limit of the IPCC projections from the start date of projections in 1990.[46]

Ocean acidification

2.39 Although carbon dioxide emissions start off in the atmosphere, a large proportion is then absorbed by the ocean as part of the natural carbon cycle. Greater carbon dioxide emissions have resulted in more carbon dioxide being dissolved into the world's oceans. Carbon dioxide forms a weak acid (carbonic acid) therefore making the ocean more acidic.[47]

2.40 The IPCC assessed that the increase in human caused carbon emissions since 1750 has led to an average decrease in pH[48] of 0.1 units and therefore an increase in ocean acidification.[49]

2.41 According to the ACE CRC, approximately half the fossil fuel carbon dioxide emitted by humans has now dissolved into the ocean. Further:

> Ocean acidification is a *direct* consequence of CO_2 emissions, so differs from the overall challenge posed by global heating in that the inevitable and inexorable rise of dissolved CO_2 in the ocean will continue independently of whether the atmosphere is warming.[50]

Predicted effects

2.42 While the exact scale and speed of future changes in the global climate are still uncertain, the direction of change is considered to be clear. The IPCC concluded that continuing greenhouse gas emissions at or above current rates would cause further warming and induce larger changes in the global climate system during the twenty first century than those observed during the twentieth century. Further:

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46 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment B,* pp. 3, 8.

47 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment C,* p. 4.

48 pH is a measure of acidity.

49 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 52.

50 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment C,* p. 4.

> …even if all greenhouse gas emissions ceased today, the Earth would still be committed to an additional warming of 0.2 to 1.0 degrees Celsius by the end of the century.[51]

2.43 Using SRES scenarios, the IPCC identified a 'best estimate' increase in global average temperature of between 1.8 degrees Celsius and four degrees Celsius at the end of the twenty first century depending upon the scenario. Sea level rise, excluding future rapid dynamical changes in ice flow, using the same scenarios, was projected to be between 0.18 and 0.59 metres.[52]

2.44 Significant effects upon ecosystems, food, coasts, industry and settlements, health and water are considered more than 80 percent likely to occur at a global level.[53] For Australia, the CSIRO has assessed that changes to the climate system will result in wide ranging impacts on natural ecosystems, cropping, forestry and livestock, water resources, public health, and infrastructure and settlement.[54]

Temperature

2.45 The CSIRO outlined a number of emissions dependent temperature scenarios for Australia for the Committee.[55] Using a midrange SRES emissions scenario, further warming of around one (0.6 to 1.5)[56] degree Celsius by 2030 is predicted. Warming will be slightly less in coastal areas and slightly more inland. There is a ten to 20 percent probability that warming will exceed one degree Celsius on the coast, and in inland regions, there was a strong possibility of temperatures exceeding 50 degrees Celsius.[57]

2.46 In relation to the projected one degree Celsius increase, the CSIRO pointed out that:

> … on our current track of emissions we are heading for a higher emissions scenario result for 2030 than that number reflects.[58]

51 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, p. 5, *Exhibit No. 7.*

52 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 45.

53 IPCC, *Climate change 2007: Synthesis report,* 2008, pp. 48-51.

54 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 19-31. *Exhibit No. 7.*

55 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 4.

56 Uncertainty range.

57 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections,* 2007, p. 4.

58 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 4.

2.47 By 2070 predicted temperature increases could be between 1.8 (1.0 to 2.5) and 3.4 (2.2 to 5) degrees Celsius, but this is strongly dependent upon the extent to which emissions are reduced over the next 30 to 40 years.[59] By 2070 in the low emissions case, there is a greater than 90 percent likelihood that warming will exceed 1 degree Celsius throughout Australia, a 20-60 percent chance of exceeding two degrees Celsius over most inland areas, and about a ten percent chance of exceeding three degrees Celsius in more coastal areas.

2.48 In the high emissions case, there is around a 30 percent chance of temperature increases exceeding three degrees Celsius in southern and eastern coastal areas and a much greater chance inland, while the chance of exceeding four degrees Celsius is around ten percent in most coastal areas and 20 to 50 percent inland.[60]

2.49 It is expected that the number of days over 35 degrees Celsius will substantially increase. For example, in the period 1971-2000, Perth averaged 28 days per year above 35 degrees Celsius. This is predicted to increase to between 35 (33-39)[61] and 54 (44-67) days. In the case of Darwin, which averages 11 days, this is predicted to increase to between 44 (28-69) and 230 (140-308) days.[62]

2.50 The CSIRO has assessed the probable effects that changes in temperature, ranging from less than one degree Celsius to more than five degrees Celsius, are likely to have on the areas identified earlier.[63] For example, at warming of one degree Celsius, areas such as the Great Barrier Reef and mountain ecosystems are considered particularly vulnerable. At higher magnitudes of warming, the CSIRO considers that annual damage to the Great Barrier Reef will increase to the point of catastrophic failure, snow cover and duration will decrease substantially, and animal, bird and plant species in northern and southeast Australia will become extinct.[64]

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59 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 4.

60 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections*, 2007, p. 4.

61 Uncertainty range.

62 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections*, 2007, p. 5.

63 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 22, 24, 26, 27, 29 and 30. *Exhibit No. 7.*

64 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 22-23, *Exhibit No. 7.*

Rainfall

2.51 While noting that rainfall is much harder to define, the CSIRO has predicted a large range in annually averaged rainfall for southern parts of Australia by 2030, ranging from no change in rainfall down to a ten percent decline.[65] In northern areas, the predicted change is around ten percent decline to five percent increase.[66] These changes will vary across regions and according to season. For example, decreases in rainfall are likely in southern areas in the annual average and in winter, in the southern and eastern areas in spring, and along the west coast in autumn.[67]

2.52 The CSIRO pointed out that the effect of greenhouse gases and the climate system on the monsoonal influences (the summer dominant rain of northern Australia) is much less clear, with more work required to understand how emissions will affect rainfall patterns.[68]

2.53 The CSIRO considers that projected changes in rainfall and increases in evaporation are likely to result in a decline in soil moisture over much of southern Australia. Simulations show that droughts are likely to increase.[69]

2.54 The vulnerability of systems to climate change can be dependant upon a number of climatic variables. For example, the impacts associated with a large temperature increase may be more modest if precipitation also increases. This is the case for agriculture, forestry and livestock, where it is expected that the interaction between temperature and precipitation will influence the impact of climate change. For warming of up to three to four degrees Celsius, wheat yields are projected to increase provided there are sufficient increases in precipitation. However, reductions in precipitation and increases in drought could have severe impacts upon agriculture.[70]

Sea levels

2.55 Sea levels are predicted to continue to rise during the twenty first century. According to the Antarctic Climate and Ecosystem Cooperative Research Centre (ACE CRC):

65 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 4.

66 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections*, 2007, p. 5.

67 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections*, 2007, p. 5.

68 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 4.

69 CSIRO and Bureau of Meteorology, *Climate change in Australia: observed changes and projections*, 2007, p. 6.

70 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 20-21, 23, *Exhibit No. 7.*

> Mitigation of greenhouse gas emissions might attenuate sea-level rise in the long-term but we are already locked into significant sea-level rise during this century.[71]

2.56 This rise is forecast to be around 0.03m in the next decade and 0.2 to 0.8m by the end of the century[72], although some scientists have suggested that these projections may have been underestimated.[73]

2.57 Thermal expansion of the ocean and glacier and ice cap melt are the two largest contributors to present sea level rise. It is considered that melting ice from Greenland and the West Antarctic Ice Sheet will become increasingly important in the future. Should these melt entirely, they contain enough ice to raise sea levels by seven metres and six metres respectively.[74]

2.58 There are significant implications both globally and for Australia from sea level rise given the densities of populations along coastlines. Urbanised coastal areas are particularly vulnerable to climate change because of their exposure to sea level rise and extreme events.

2.59 Some of the specific implications of sea level rise for Australia identified by the ACE CRC include:

- More frequent extreme sea level events. It is predicted that events that presently occur every few years may occur every few days in 2100 if mean sea level rises by 0.5m. Sydney, Brisbane and Bass Strait are considered particularly likely to see larger increases in the frequency of these events.[75] Sea level rise off the east and west coast of Australia has already resulted in extreme sea level events of a given magnitude occurring roughly three times as often in the last half of the twentieth century compared with the first half.[76]
- Shoreline recession. For a sea level rise of 0.5m, it is predicted that landward erosion of about 50m will occur on sandy beaches. Other high

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71 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A*, p. 7.

72 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A*, p. 7.

73 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A*, p. 11.

74 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A*, p. 8.

75 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A*, pp. 12-13.

76 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment B*, p. 8.

energy exposed coasts (such as those around much of southern Australia) will experience higher rates of recession while very low energy or embayed coasts (such as those across much of tropical Australia) are likely to experience lower rates.[77]

- Flooding of low lying islands. Many islands are exposed to the risks not only of flooding but also more frequent high sea level events.[78]

2.60 In relation to extreme events, the CSIRO told the Committee that:

> One of the big issues with climate change is not some of the slow-moving trends that you see in temperature or rainfall, it is the combination of that trend with extreme events. If there is a combination of some sea level rise and then an extreme weather event, the storm surge that is a result of that has a very large impact, particularly in our coastal areas.[79]

2.61 For example, in this context Kakadu is an area that is particularly vulnerable due to salt water coming into the Kakadu wetlands.[80]

Ocean acidification

2.62 More carbon dioxide in the oceans is lowering the availability of dissolved carbonate ions to calcifying organisms such as shelled sea animals and corals. Calcifying organisms need this carbonate to precipitate their shells.

2.63 According to the ACE CRC, ocean acidification can be considered an impact 'advancing from the south' and one that will affect Australia's marine ecosystems in the Southern Ocean, marine protected areas on the southern margins of the Australian continent (the Great Australian Bight and Tasmanian seamounts) and eventually the Great Barrier Reef.[81] The Southern Ocean, as a cold mass of water, contains a disproportionate amount of human caused carbon dioxide compared with other warmer oceans. The Antarctic polar waters are expected to be the first to experience carbonate ion concentrations low enough that aragonite, one

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77 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A*, p.12.

78 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment A*, p. 12.

79 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 5.

80 Dr Andrew Ash, *Transcript of Evidence,* 1 December 2008, p. 5.

81 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment C*, p. 6.

form of calcium carbonate, will no longer be able to be precipitated by shell-forming organisms.[82]

2.64 In its submission, the Great Barrier Reef Marine Park Authority (GBRMPA) cited modelling undertaken by the CSIRO and based on SRES, which forecast that the annual sea surface temperature of the Great Barrier Reef will increase between 1.2 degrees Celsius and 3.9 degrees Celsius by 2080. However, in addition to increased sea surface temperatures, ocean acidification will have far reaching effects.[83] It is predicted that ocean pH will decrease between 0.3 to 0.5 units by 2100.[84] GBRMPA informed the Committee that:

> ocean acidification is of concern to coral reefs as calcium carbonate binding organisms (such as corals) are unable to form their skeletons. Scientific evidence suggests that if CO_2 concentrations rise above 500 parts per million, corals will be unable to grow. [85]

2.65 GBRMPA also told the Committee that once carbon dioxide level rises above 450 parts per million hard corals will struggle to grow and build skeletons strong enough to withstand storm damage. As a consequence, there will be fewer hard corals and increasingly abundant soft corals, algae and seaweed. This then means that the reef system will:

> shift away from the system as we know it now towards a system that has lower productivity in terms of many of the commercial species extracted from the Great Barrier Reef and also lower values in terms of the aesthetics that support the tourism industry.[86]

2.66 Coral bleaching is a stress response to high temperatures. Bleaching events of a high magnitude have only been seen in the last ten to 15 years. In the last ten years there have been three bleaching events in the Great Barrier Reef, which is a higher frequency than has ever been seen previously in a ten year timeframe. GBRMPA considers that this is reflective of an increasing trend in baseline temperatures. [87] In addition, there have been unusually warm sea surface temperatures in the years when bleaching events have occurred. [88] While these events have affected the quality of the reef, no coral species have yet been lost because of these warm water

82 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment C,* p. 6.

83 Dr Paul Marshall, *Transcript of Evidence,* 9 December 2008, p. 37.

84 Great Barrier Reef Marine Park Authority, *Submission No. 19,* p. 1.

85 Great Barrier Reef Marine Park Authority, *Submission No. 19,* p. 1.

86 Dr Paul Marshall, *Transcript of Evidence,* 9 December 2008, p. 31.

87 Dr Paul Marshall, *Transcript of Evidence,* 9 December 2008, p. 36.

88 Dr Paul Marshall, *Transcript of Evidence,* 9 December 2008, p. 35.

events.[89] However, once affected by bleaching, coral reefs are at much greater risk, particularly if they do not have sufficient time between bleaching events to recover.[90]

2.67 Ocean acidification is also likely to impact upon the key components of the benthic habitats on which many fisheries in Australian waters are dependent. It will also affect gastropods such as abalone and bivalves including oysters and mussels. In the medium to long term there are likely to be impacts upon fisheries and aquaculture management and practices, including the species produced and areas suitable for production.[91]

What is an acceptable level of carbon in the atmosphere?

2.68 To maintain a stable level of carbon dioxide in the atmosphere, global emissions of carbon dioxide must be reduced to a level that prevents any net accumulation of carbon dioxide in the atmosphere.

2.69 In the IPCC Special Report on Emissions Scenarios (SRES), a range of emissions scenarios were examined based upon different assumptions about future economic, technological and social changes without specific policies to reduce greenhouse gas emissions. All the scenarios suggested that emissions would be at least two to four times 1990 levels by 2050 and may be as high as five times 1990 levels by 2100.[92] Therefore:

> …it is clear that achieving no net growth in atmospheric concentrations requires reversing the current trend of increasing GHG emissions – ultimately reducing emissions to levels well below those of 1990.[93]

2.70 The CSIRO has examined various attempts to define the global mean temperature change and/or stabilisation level consistent with the concept of dangerous human caused interference.[94] The stabilisation targets

89 Dr Paul Marshall, *Transcript of Evidence,* 9 December 2008, p. 32.

90 Dr Paul Marshall, *Transcript of Evidence,* 9 December 2008, p. 33.

91 Antarctic Climate and Ecosystems Cooperative Research Centre, *Submission No. 31, Attachment C,* p. 10.

92 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, p.12, *Exhibit No. 7.*

93 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, p. 12, *Exhibit No. 7.*

94 Article II of the United Nations Framework Convention on Climate Change (UNFCCC) identified the objective of 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous human caused interference with the climate system' but did not identify what this level should be.

identified ranged from 375 to 550 parts per million with temperature targets ranging from 0.9 to 2.9 degrees Celsius above 1990 levels.[95]

2.71 There is growing support amongst climate scientists and experts that the global average temperature increase should be no more than a maximum of two degrees Celsius. This includes the average temperature increase of 0.6 degrees Celsius which has already occurred since industrialisation.[96] For example, the 2007 Bali Climate Declaration by Scientists stated in relation to a future global climate treaty:

> The prime goal of this new regime must be to limit global heating to no more than 2°C above the pre-industrial temperature, a limit that has already been formally adopted by the European Union and a number of countries.
>
> Based on current scientific understanding, this requires that global greenhouse gas emissions need to be reduced by at least 50% below their 1990 levels by the year 2050. In the long run, greenhouse gas concentrations need to be stabilised at a level well below 450ppm (parts per million; measured in CO2-equivalent concentration). In order to stay below 2°C, global emissions must peak and decline in the next 10 to 15 years…[97]

2.72 In its submission, Greenpeace also argued that to prevent dangerous climate change, global temperature rise must be kept as far below two degrees Celsius as possible, compared with pre-industrial levels. According to Greenpeace, the goal of climate policy must be to ensure that global emissions peak as soon as possible and are substantially reduced in the very near term, with global emissions peaking in 2015 and reduced by more than 50 percent by 2050 with reductions continuing thereafter.[98]

2.73 The Climate Institute argued that even a two degree Celsius increase in global temperatures would result in severe impacts for Australia. It considered that concentrations need to peak well below 500 parts per million and then decline to levels below 400 parts per million over the coming centuries.[99]

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95 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 10 and 11, *Exhibit No. 7.*

96 NSW Greenhouse Office, *NSW greenhouse plan,* November 2006, p. 11; The Climate Institute, *Submission No. 15,* p. 8.

97 2007 Bali Climate Declaration by Scientists, www.ccrc.unsw.edu.au/news/2007/Bali.html, viewed on 2 February 2009.

98 Greenpeace, *Submission No. 24,* p. 3.

99 The Climate Institute, *Submission No. 15,* p. 4.

2.74 Figure 2.1 is reproduced from the IPCC's 2007 report and summarises the required emission levels to achieve different stabilisation concentrations and the resulting global average temperature increases. As can be seen from the table, in order to stabilise at a lower concentration and temperature level, emissions will need to peak earlier and greater emission reductions are required by 2050.[100]

Figure 2.1 IPCC stabilisation scenarios

Table 5.1. *Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.[a] {WGI 10.7; WGIII Table TS.2, Table 3.10, Table SPM.5}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:
a) The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).
b) Atmospheric CO_2 concentrations were 379ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO_2-eq.
c) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure 2.1).
d) The best estimate of climate sensitivity is 3°C.
e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 30).
f) Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

Source *IPCC, Climate Change 2007: Synthesis Report, p. 67.*

2.75 Global average temperature increase is expected to slow within a few decades of greenhouse gas emissions being stabilised. However, according to the IPCC, small increases in temperature can be expected for several centuries.[101]

2.76 Figure 2.1 also includes global average sea level rise. Sea level rise from thermal expansion will continue for many centuries after greenhouse gas concentrations are stabilised due to ongoing heat uptake by the oceans. In addition to thermal expansion, the implications of Greenland ice sheet loss, as noted earlier, are potentially several metres and would have major consequences for world coastlines.[102]

100 IPCC, *Climate change 2007: Synthesis report*, 2008, p. 67.

101 IPCC, *Climate change 2007: Synthesis report*, 2008, p. 66.

102 IPCC, *Climate change 2007: Synthesis report*, 2008, pp. 66, 67.

2.77 The IPCC considered that delaying emission reductions would significantly constrain the opportunity to achieve lower stabilisation levels and increase the risk of more severe climate change. In contrast, it considered that mitigation measures over the next two to three decades 'will have a large impact on opportunities to achieve lower stabilisation levels'.[103]

2.78 The stabilisation level that is ultimately adopted will depend upon what climate change impacts governments are prepared to accept. Scientific evidence presented by bodies like the IPCC and CSIRO have outlined the likely impacts that increases in temperature will have.[104] The Garnaut Climate Change Review has also made detailed comparisons of the likely impacts of a 'strong' global mitigation scenario (550 parts per million carbon dioxide equivalent stabilisation) and 'ambitious' global mitigation scenario (450 parts per million carbon dioxide equivalent stabilisation).[105] For example, the world's natural ecosystems are considered particularly vulnerable to climate change with patterns of temperature and precipitation affecting the distribution and abundance of species. The IPCC has assessed that a one to two degrees Celsius increase in global mean temperature would pose a significant risk to many ecosystems.[106] For Australia, the potential impacts upon one significant ecosystem, the Great Barrier Reef, have already been discussed. In its evidence, the GBRMPA informed the Committee that the best possible outcome for the Great Barrier Reef would be for Australia and other countries to rapidly adopt targets that will stabilise atmospheric carbon dioxide well below the critical threshold of 450 parts per million:[107]

> According to world-class coral reef scientists, a dramatic loss in coral reef biodiversity is inevitable at atmospheric CO_2 concentrations approaching 500 parts per million. Other ecosystems are likely to be extremely impacted at atmospheric CO_2 concentrations between 450 to 500 parts per million. Therefore, it is crucial for coral reefs and other ecosystems that emissions are

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103 IPCC, *Climate change 2007: Synthesis report*, 2008, p. 66.

104 IPCC, *Climate change 2007: Synthesis report*, 2008, pp. 48-54; Preston, B.L. and R.N. Jones, *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions,* A consultancy report for the Australian Business Roundtable on Climate Change, February 2006, pp. 19-31. *Exhibit No. 7.*

105 Garnaut, R., *The Garnaut climate change review* 2008, p. 279.

106 IPCC, *Climate change 2007: Synthesis report*, 2008, pp. 64-65.

107 Great Barrier Reef Marine Park Authority, *Submission No. 19*, p. 2.

> effectively managed to maintain atmospheric CO_2 well below these critical thresholds.[108]

2.79 The availability of water resources and water stresses are another critical issue on a global basis.[109] The CSIRO has argued that the current pressures placed on Australian water resources 'are indicative of their general high vulnerability to climate change'.[110] With predicted declines in rainfall, particularly across southern Australia, climate change is likely to impact upon:

- important water catchment areas, by impacting on the growth, species composition, frequency and severity of fire and pest incursion of the native forest that covers many of these areas;
- water supply and water quality for irrigation and other uses;
- inflows into reservoirs; and
- wetlands important for bird breeding and other wildlife.[111]

2.80 As an example, a one to two degree Celsius increase in temperature is projected to lead to a 12 to 25 percent decrease in flow in the Murray Darling Basin and a seven to 35 percent decrease in Melbourne's water supply.[112]

2.81 While the CSIRO considered that limiting future increases in atmospheric carbon dioxide to 550 parts per million could avoid the more extreme climate changes, a lower stabilisation level, such as 450 parts per million:

> …would give natural ecosystems and their associated species greater time to adapt to changing environmental conditions, reduce the likelihood of major adverse consequences for agriculture and forestry, help ensure that Australia's public health infrastructure can keep pace with emerging health challenges, and reduce the chance of large-scale singularities.[113]

2.82 In its submission, The Climate Institute argued that:

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108 Great Barrier Reef Marine Park Authority, *Submission No. 19,* p. 1.

109 IPCC, *Climate change 2007: Synthesis report,* 2008, p. 49.

110 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, p. 25, *Exhibit No. 7.*

111 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 25-26, *Exhibit No. 7.*

112 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, p. 26, *Exhibit No. 7.*

113 Preston, B.L. and Jones, R.N., *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions,* 2006, pp. 5-6, *Exhibit No. 7.*

- A stabilisation level of 400 parts per million or below will reduce the risk of irreversible and potentially catastrophic global impacts, although there will still be risks to natural systems such as coral reefs.
- An objective of stabilising atmospheric concentrations at 450 parts per million, 'suggests that Australia is prepared to accept the known adaptive capacity of Australian natural ecosystems being exceeded'. It also risks the known adaptive capacity of water security and coastal communities.
- At 550 parts per million, the risks include severe drought constraining water supplies and farming over large areas, catastrophic events such as collapse of the Greenland and West Antarctic icesheets and exceeding the known adaptive capacity of Australian natural ecosystems, water security, coastal communities, agriculture, forestry, tourism and health systems.[114]

2.83 The projections of the IPCC, CSIRO and other scientists have identified the likely impacts of global heating and clearly illustrate that it is in Australia's national interest to ensure global temperatures peak at the lowest possible level.

2.84 While it is no longer possible to avoid all the adverse impacts of global climate change, reductions in greenhouse gas emissions can limit the magnitude and rate of future climate change.

2.85 The Committee notes that a stabilisation target of 450 parts per million carbon dioxide equivalent is considered to provide about a 50 percent chance of limiting the global mean temperature increase to two degrees Celsius above pre-industrial levels.

2.86 Stabilisation at a higher level, such as 550 parts per million is associated with a real risk of dangerous climate disruption.

2.87 On the basis of the evidence available to it, the Committee considers that a stabilisation target for greenhouse gas emissions that provides the best opportunity to protect significantly threatened areas such as the Great Barrier Reef, as well as natural and human environments more broadly, from the effects of climate change, should be adopted.

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114 The Climate Institute, *Submission No. 15,* p. 10.

Recommendation 1

The Committee finds that it is in Australia's interests to secure global agreement to deliver deep cuts in emissions so as to stabilise concentrations of greenhouse gases in the atmosphere at 450 parts per million or lower by 2050.