



## **Climate change research priorities for NSW primary industries Discussion paper**

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# Climate change research priorities for NSW primary industries

## Discussion paper

Prepared by NSW DPI for the Ministerial Advisory Council on Primary Industries Science

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The information contained in this publication is based on knowledge and understanding at the time of writing (October 2007). However, because of advances in knowledge, users are reminded of the need to ensure that information on which they rely is up to date and to check the currency of the information with the appropriate officer of New South Wales Department of Primary Industries or the user's independent advisor.

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## FOREWORD



Much information has been released indicating enhanced temperatures in recent decades. Many scientists attribute these increases to anthropogenic activities. These studies lead to a global need to reduce our carbon emissions. Clearly agriculture will go through a process of review. Its carbon emitting processes will come under increasing scrutiny. It is vital that we be prepared. DPI science and research has a vital role to play in this reevaluation.

Some of the scenarios by climatologists indicate potential impacts for primary industries. These include an increase in temperatures, as well as a reduction in rainfall in our key water catchments and those areas most heavily used for agriculture and forestry. Climatic events such as droughts and floods are also projected to become more severe. There will also be impacts on fish resources as rises in sea levels affect key fish breeding grounds, while the mining sector will face significant challenges responding to community demands for reduced emissions. While the jury is still out on what impacts will eventuate, it is prudent to plan.

Australia is one of the biggest emitters of greenhouse gases per person in the world, and is the ninth-largest emitter in absolute terms. Twenty-eight per cent of Australia's total emissions are produced by NSW. Primary industries, like other sectors of the economy, have a role to play in reducing greenhouse gas emissions and in capturing and sequestering carbon from the atmosphere. However, even if we were successful in halting the current rate of increase in emissions, some further global warming is expected because of the lagged effect of past emissions. As a result, primary industries need to be able to better understand the likely impacts of climate change and develop strategies to manage the risks from climate change, as well as take advantage of any opportunities it may present.

Because there are so many unknowns in relation to climate change, there needs to be an initial emphasis on research in order to quantify the likely impacts and develop practical solutions. Late last year, I asked my Ministerial Advisory Council on Primary Industries Science to provide me with advice on those research priorities that should be addressed by the NSW Department of Primary Industries (DPI). This document is a discussion paper that was prepared by NSW DPI to assist the Advisory Council in their deliberations. The Advisory Council were so impressed with the paper that they suggested it be published in its own right, because of the wealth of background information it contains and the synthesis of current scientific thinking it provides. The original document has been updated to incorporate the recommendations of the Advisory Council and recent projections by the Intergovernmental Panel on Climate Change.

In response to these developments I have established the Office for Rural Greenhouse Gas Studies within the Primary Industries Innovation Centre, a collaborative joint venture with the University of New England. The Office will be a national powerhouse of research providing new innovations to reduce greenhouse gas emissions, including bioenergy and low emission farming and methane abatement.

The discussion paper not only provides a blueprint for future NSW DPI research on climate change, but provides a significant input into broader inter-jurisdictional deliberations currently underway by the Primary Industries Ministerial Council, and in developing collaborative research arrangements with other agencies and jurisdictions.

The paper also provides a very readable summary of the science of climate change and the implications for primary industries in NSW.

IAN MACDONALD

MINISTER FOR PRIMARY INDUSTRIES | MINISTER FOR ENERGY |  
MINISTER FOR MINERAL RESOURCES | MINISTER FOR STATE DEVELOPMENT

## EXECUTIVE SUMMARY

There are a number of natural influences on the world's climate, including changes to the Earth's orbit, volcanic and meteorite activity and tectonic upheaval. There is, however, mounting evidence that human activity is increasing the concentration of greenhouse gases in the atmosphere, thus enhancing the greenhouse effect. Greenhouse gases have the capacity to trap heat, by allowing the transmission of incoming (short-wave) radiation from the sun, whilst impeding outgoing (long-wave) radiation from leaving the earth.

The greenhouse gas that is contributing most to the enhanced greenhouse effect is carbon dioxide. Fossil fuel combustion (for electricity and transport) and deforestation have increased carbon dioxide concentration to 36% above pre-industrial levels. Other greenhouse gases, such as methane, nitrous oxide and water vapour, also contribute significantly to the greenhouse effect.

Australia has one of the highest rates of emission per person in the world, and is the ninth-largest emitter in absolute terms, producing about 1.8% of total world greenhouse gas emissions. Australia's total emissions in 2005 were 559Mt, of which 158Mt (28%) were produced by NSW. The energy sector makes the largest contribution to NSW greenhouse emissions, accounting for 71% of emissions in 2005 (111Mt). Electricity generation, which was mostly coal-fired, accounted for 52% (57.8Mt) of the emissions from the energy sector. Transport and agriculture accounted for 19% (21.6Mt) and 16% (18.6Mt), respectively, of the total 2005 emissions from NSW. Livestock was the largest contributor to the agricultural sector (14.5Mt), primarily due to methane emissions from ruminant animals. Total NSW emissions have remained relatively stable from 1990 to 2005; however, this is due to greatly reduced rates of land clearing and increased reforestation, resulting in a 13.8 Mt reduction in emissions from the land use, land use change and forestry (LULUCF) sector, which has offset substantial increases in emissions by other sectors, particularly power generation (up 29%) and transport (up 17%).

The national emissions profile has a similar sectoral composition to the NSW profile. The energy and agriculture sectors contribute 64% and 16%, respectively, to the national total. Emissions from LULUCF decreased by 95.2 Mt CO<sub>2</sub>-e (74%) between 1990 and 2005, largely offsetting a 104 Mt (36%) increase in energy sector emissions. Consequently, national emissions increased by 2.2% in that period. It is predicted that Australia will face significant growth in emissions over the next 50 years if a 'business as usual' approach is taken. There is growing consensus that it is critical to stabilise atmospheric carbon dioxide at 550 ppm or less to avoid catastrophic impacts, which will require developed countries to reduce their emissions by 60% below 1990 levels by 2050.

The increase in emissions of greenhouse gases (particularly CO<sub>2</sub> from combustion of fossil fuels) has altered atmospheric composition, and is increasing global temperatures and affecting global and regional climate systems. A number of changes have been observed in the NSW climate; however, the extent to which these can be attributed to climate change is uncertain. Temperature increased by 0.9°C between 1910 and 2005. There are also indications that the rainfall pattern is shifting: since 2000, the state average has returned to the averages experienced in the dry first half of last century, and has been 20% lower than the average rainfall received in the second half of that century.

Even if emissions are capped at today's levels, some further warming is expected, due to the lagged effects of past greenhouse gas emissions. Impacts on rainfall are much harder to assess, but current projections suggest that it is likely to be reduced in the highly populated areas of Australia, as well as zones of major agricultural and forestry production. Climate change is predicted to increase average temperatures in NSW by 0.7° to 6.4°C by 2070, with the greatest increase in the west of the state. Rainfall is likely to decrease everywhere other than the north-east. Projections suggest a reduction in frosts (though their severity may be increased) and an increased incidence of hot days, bushfire and intense storms. Drought frequency may increase, especially in winter and spring. Reduced rainfall will lead to an even greater reduction in runoff, increasing pressure on water resources. These

predicted impacts of climate change are likely to have serious negative impacts on all NSW primary industries, and consequently on the NSW economy.

While plant growth may be enhanced by the 'CO<sub>2</sub> fertilisation effect' and increased water use efficiency (a direct effect on plant physiology of elevated atmospheric CO<sub>2</sub> concentration), productivity increases will be limited by water and nutrient availability. Wheat yields may be enhanced, though greater variability in average rainfall and increased incidence of drought are likely to increase yield variation. Temperature changes may alter the planting window and length of the growing season, which may restrict the options, particularly for summer crop species. Irrigated cropping is likely to be severely restricted in some years by limited water availability. Product quality is threatened by climate change, particularly in the wheat, cotton and wine industries. The growth rate of forests may be increased, but the high risk of bushfire and a possible increase in the impacts of pests and disease will threaten forest carbon stocks. Animal industries are likely to suffer increasing heat stress, which will affect growth rates, egg and milk production, and reproduction. The rising sea level (due to thermal expansion of the oceans and melting of polar ice caps and mountain glaciers), storms, reduced stream flow and salt water incursion into estuaries are likely to affect fish stocks, by impacting on breeding. Fisheries may also be affected by increasing ocean acidity. The mining industry is likely to be severely impacted upon by measures to mitigate emissions from coal-fired power generation.

It is clear that all primary industries will be substantially affected by climate change. It is critical, therefore, that a concerted effort is made to mitigate emissions from all sectors, including the primary industries sector. Also, knowing that some change is inevitable, the primary industries must develop the capacity to adapt to climate change.

Reducing emissions (as part of an international approach) would prevent some of the worst-case scenarios of climate change from occurring in Australia. All NSW primary industry sectors have a role to play in reducing emissions. Mitigation options include the capture and storage of carbon dioxide emissions from power stations; reduction in methane emissions from ruminant livestock; management of crop, pasture and forest systems to enhance carbon stocks in vegetation and soil, and to reduce N<sub>2</sub>O emissions; and use of agricultural and forest biomass for bioenergy. Research is required to enhance available mitigation options.

The government has a range of policy responses available to address climate change through the provision of direct or indirect incentives for the implementation of available mitigation measures – from subsidies, penalties and taxes to market-based mechanisms and funding for research and education programs. All levels of government are examining available options. In NSW, the Greenhouse Plan encapsulates the current suite of policy responses. Of particular relevance to NSW Department of Primary Industries (NSW DPI) is emissions trading, which provides incentives for mitigation measures, and opportunities for research, extension and education.

Emissions trading is considered an effective and cost-efficient means of providing an incentive for industries to efficiently reduce greenhouse gas emissions. The NSW Greenhouse Gas Abatement Scheme (GGAS) was the first mandatory emissions trading scheme in the world. The National Emissions Trading Taskforce, established by the first ministers of the state and territory governments, has released a proposal for a national emissions trading scheme. The proposed scheme includes incentives for sequestration through reforestation and carbon capture and storage. Sequestration through soil carbon management in agricultural systems, and management of existing forests, are flagged for future inclusion. An emissions trading scheme will be important in providing the incentive for industry to adopt solutions developed through further research; however, further research is also required to underpin the effective operation of the emissions trading scheme itself.

Over the past decade, NSW DPI has been conducting research into both mitigation and adaptation strategies to limit emissions and assist with developing new systems that are sustainable in the face of climate change. This paper synthesises these research efforts, and focuses on the research priorities for NSW DPI in responding to the major challenges that climate change brings to the portfolios for which NSW DPI has responsibility.

The research needs identified can be summarised as:

- developing predictive capacity, to better understand the likely impact of climate change on key NSW primary industries, at the regional level
- enhancing ability to mitigate emissions in all primary industry sectors
- developing a capacity for adaptation to inevitable climate change in all primary industry sectors.

Specific research priorities include:

#### **Climate change modelling**

- Development of regional climate change models through downscaling of global climate projections.
- Development of a Geographical Information System (GIS) based framework for assessing the risk of climate change for primary production systems.
- Vulnerability assessment of key systems to test the capacity for the coping range to be extended by proposed adaptation strategies.
- Assessment of the socioeconomic impacts of climate change.
- Development of decision support systems to assist primary industries in coping with enhanced climate variability.

#### **Climate change mitigation**

- Research into clean coal technologies, through:
  - identification of sites suitable for geosequestration, and subsequent development of pilot injection projects
  - trial of capture of CO<sub>2</sub> from power generation plants, gasification, and chemical looping technologies
  - investigation of the potential for algal photobioreactor systems, growing algae to produce biodiesel, using carbon dioxide captured from power stations.
- Research into mitigation options in agriculture and forestry, through:
  - full life cycle analysis of current and alternative farming and forest systems, including direct and indirect emissions and removals
  - development of sustainable production systems with enhanced carbon sequestration and lower life cycle emissions, that have the capacity to adapt to climate change
  - research into methods of reducing methane emissions from ruminant livestock, managing emissions from manure in intensive livestock industries, and reducing nitrous oxide emissions from applied fertiliser
  - research into the use of char and other recycled organics as a soil amendment.
- Development of technologies for the production of bioenergy and other products from biomass, through:
  - examination of a range of feedstocks (including woody plants) and alternative energy conversion technologies
  - assessment of the socioeconomic impacts of a bioenergy industry on other NSW primary industries
  - assessment of potential to produce high value chemicals from biomass.
- Development of the supporting science to facilitate mitigation through emissions trading, through:
  - development of improved models of soil carbon dynamics, sequestration of dryland forest species and mixed-species revegetation

- research into the role of forest products in climate change mitigation
- development of greenhouse accounting methods for use in inventory calculation and emissions trading that:
  - recognise the role of wood products in climate change mitigation
  - provide an incentive for management practices that reduce emissions or enhance sequestration in agricultural and forestry systems
  - are cheap to use, thereby facilitating inclusion of small-scale revegetation projects.

In developing agricultural and forestry systems to help mitigate climate change, we need to consider three key criteria:

1. life cycle greenhouse gas and energy balance, to ensure systems deliver benefits in these areas
2. sustainability of production systems, including impacts on all environmental attributes
3. adaptation capacity of new systems.

### **Climate change adaptation**

- Development of resilient agricultural and forestry production systems with increased capacity to cope with climate variability, trends in climate variables, and indirect impacts (e.g. fire, pests) anticipated under climate change, for example:
  - breeding for faster grain filling, reduced chilling requirement, tolerance of higher temperatures, shorter growing seasons and reduced water availability
  - research into the interactive effects of increased atmospheric carbon dioxide in a water- and nutrient-limited environment on growth of major crop, pasture and forest species
  - research into the impacts of climate change on product quality, pests and diseases
  - development of strategies for minimising water losses, both on-farm and on a regional scale
  - improving water use efficiency for irrigated agriculture, while minimising increased energy requirements.
- Research into sustainable development of marine and freshwater ecosystems, to ensure that they are both ecologically healthy and economically productive under the predicted impacts of climate change, for example:
  - evaluation of the impacts of alternative management strategies
  - robust monitoring systems to understand the impacts of climate change
  - research into the impact of climate change on ecological health
  - evaluation of proposed adaptation strategies for marine and freshwater fisheries
  - research into the impacts of increasing acidity of the oceans
  - research into the impacts of sea level rise on estuarine salt marsh communities.

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## 1 WHAT IS CLIMATE CHANGE?

Earth's climate varies over time scales, from months through to centuries and beyond. Factors that affect the climate over time scales from hundreds to millions of years include energy output from the sun, variation in the Earth's orbit and the orientation of its axis, the greenhouse effect of water vapour and other trace gases, volcanic and meteorite activity and plate tectonics (movement of the continents). Glacial cycles, for example, are driven by wobbles in the Earth's orbit. Greenhouse gases and polar ice sheets respond to this wobble and enhance the warming/cooling cycle of the earth by 2° to 3°C. Other natural phenomena cause variability at decadal and inter-annual scales: changes in sea surface temperature, ocean currents and the associated changes in the atmospheric circulations (e.g. the El Niño-Southern Oscillation). The resultant changes to the climate from these phenomena are considered to be natural variation.

The term 'climate change' commonly refers to influences on climate resulting from human practices. Increases in the concentration of so-called 'greenhouse gases' in the atmosphere, resulting largely from burning of fossil fuels and deforestation, have led to an observed and projected warming of the Earth, known as the enhanced greenhouse effect. It is not easy to distinguish this anthropogenic climate change from the natural variations in the drivers described above.

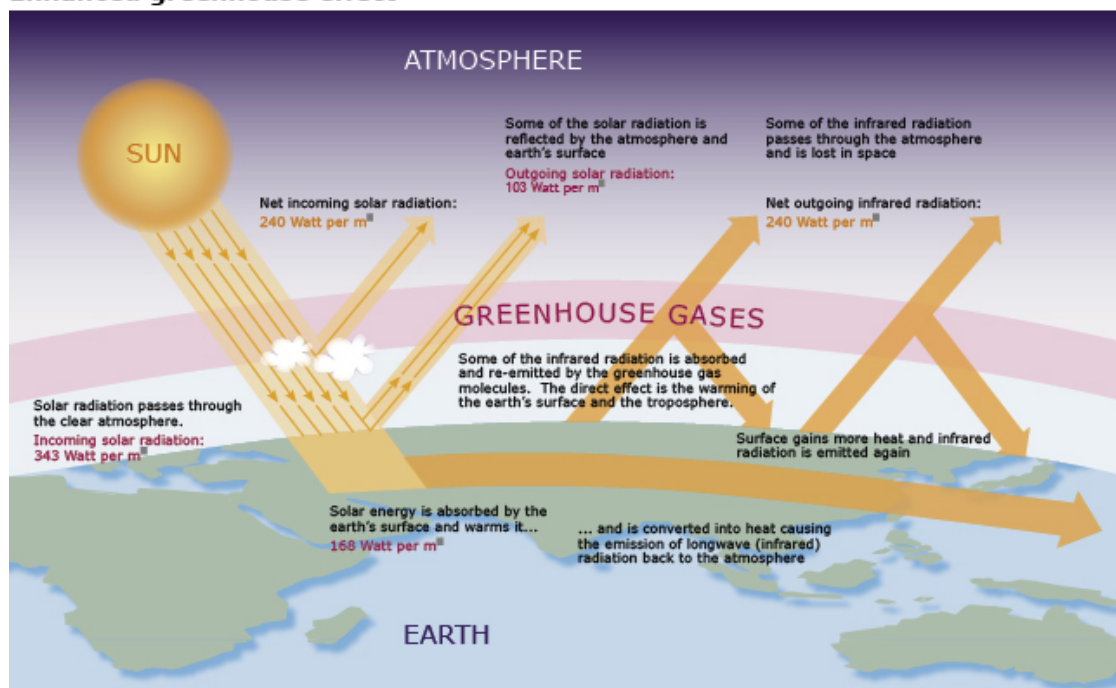
The study of the climate and its variations, extremes and shifts is not a new science; Svante Arrhenius suggested in 1896 that burning of fossil fuels might cause an increase in carbon dioxide in the atmosphere and in turn warm the Earth (Pittock 2003). However, the recent succession of unusually warm years and extreme climatic events has heightened awareness, and climate change is now a mainstream media topic, in recent times moving to headline status. The intensity of interest is placing considerable pressure on the capacity of the scientific community to respond to the concerns being raised.

Until very recently, much of the media attention centred on the sceptics who put up counter-arguments to the existence of climate change, pointing to the 5°C difference in global average temperatures between the glacial and inter-glacial periods (> 10 000 year cycles) as evidence that recent temperature trends are within normal variation (Pittock 2003). These sceptics played a very important role in forcing the scientists to produce evidence of rigorous analysis of their scenarios and projections. If current trends continue, scientists predict temperature rises of up to 5°C over the next century, causing major perturbation of natural and human systems.

## 2 WHAT CAUSES CLIMATE CHANGE?

The Earth would be much colder if not for the greenhouse gases, which provide a blanket that warms the atmosphere. Some of the gases in the atmosphere transmit the short-wave radiation from the Sun to the Earth, warming its surface. Some of this warmth is emitted in the form of long-wave (infrared) radiation from the Earth to the atmosphere, and some of the gases in the atmosphere absorb and re-emit radiation of this wavelength, effectively enhancing the warming of the lower atmosphere (Figure 1). These gases are called greenhouse gases because their effect is similar to the function of a glass greenhouse, which heats up as infrared radiation is trapped by the glass. The main greenhouse gases are water vapour, carbon dioxide, methane and nitrous oxide, all of which occur naturally in the atmosphere.

## Enhanced greenhouse effect



**Figure 1. The enhanced greenhouse effect (source: CRC for Greenhouse Accounting 2006).**

Water vapour is the major contributor to the greenhouse effect. Water vapour concentrations fluctuate regionally due to natural impacts, and human activity generally does not directly affect water vapour concentrations, except on very local scales. However, climate models are now predicting that the concentration of water vapour in the upper troposphere may increase in response to increasing concentrations of other greenhouse gases (Steffen 2006). This increase in water vapour could play a key role in amplifying the rate at which the climate warms (Soden et al. 2005).

The gases that contribute directly to the enhanced greenhouse effect as a result of anthropogenic activities are carbon dioxide, methane and nitrous oxide (emitted from combustion of fossil fuels, deforestation and agriculture) and sulfur hexafluoride, perfluorocarbons and hydrofluorocarbons (arising from industrial processes). It is these six gases that are controlled under the UN Framework Convention on Climate Change<sup>1</sup>. Some other gases, including carbon monoxide, nitrogen oxides and volatile organic compounds, contribute indirectly to global warming through chemical reactions in the atmosphere. Other emissions, such as sulfate aerosols, have a cooling or dimming effect on the climate, as they reflect some of the short-wave radiation before it reaches the Earth's surface.

The contribution of each of the greenhouse gases to global warming is dependent on its global warming potential (GWP), expressed as carbon dioxide equivalent ( $\text{CO}_2\text{-e}$ ). The GWP takes into account:

- the amount of radiation that the gas absorbs and the wavelength at which it absorbs
- the time that the gas stays in the atmosphere before reacting or being dissolved in rainwater or the ocean
- the current concentration of the gas in the atmosphere
- any indirect effects of the gas (e.g. methane will produce ozone gas in the lower atmosphere and water vapour in the stratosphere).

The GWP of nitrous oxide is 298 times that of carbon dioxide, and methane is 25 times that of carbon dioxide, when considered over 100 years (Solomon et al. 2007).

<sup>1</sup> The halogenated hydrocarbons, also potent greenhouse gases released from industrial processes, are controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer.

The concentration of CO<sub>2</sub> in the atmosphere in 2005 was 379 ppm (compared with the pre-industrial value of 280 ppm), and is rising at 1.9 ppm per year (1995–2005 average) (Solomon et al. 2007). The increase in concentration of greenhouse gases in the atmosphere has altered the Earth's radiative balance, resulting in more of the sun's heat being absorbed and trapped inside the Earth's atmosphere, producing global warming. Without mitigation measures, the concentration of CO<sub>2</sub> in the atmosphere is predicted to rise to at least 650 ppm, and up to 1200 ppm, by 2100 (IPCC 2001a), which is expected to increase average global temperature by 1° to 6°C. Most scientists agree that global warming caused by anthropogenic greenhouse gas emissions is one of the most serious environmental problems facing the world today, with far-reaching consequences for all sectors of society. To avert catastrophic impact, it is generally agreed that atmospheric CO<sub>2</sub> concentration should be constrained to 550 ppm, which it is believed will limit the temperature increase to 2°C.

### **3 AUSTRALIAN EMISSIONS PROFILE**

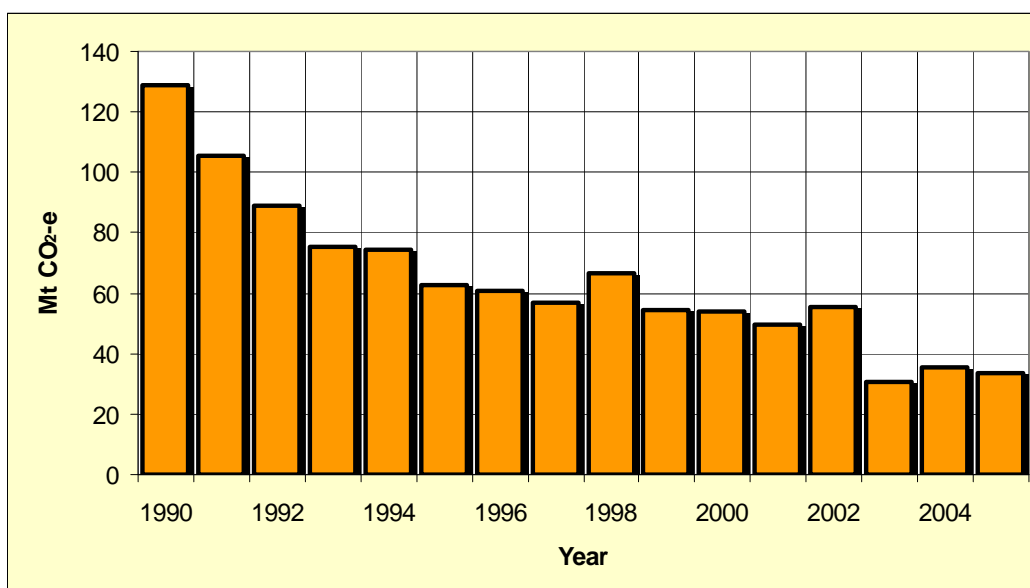
#### **3.1 NATIONAL EMISSIONS PROFILE**

Australia has one of the highest rates of emission per person in the world, and is the ninth-largest emitter in absolute terms, producing about 1.8% of total world greenhouse gas emissions (UNFCCC 2006b; UNFCCC 2006c). Australia's largest source of greenhouse gas emissions is the stationary energy sector, which includes fossil fuel combustion for electricity and heat production, and energy use in the manufacturing and construction industries. The second-largest contributor is the transport sector. Stationary energy, transport and fugitive emissions associated with the extraction of fossil fuels together contributed about 70% of emissions in 2005. Agriculture contributed 16% of 2005 emissions, largely from enteric fermentation of cattle and sheep. Land clearing emitted 53.3 Mt CO<sub>2</sub>-e, while the sink value of reforestation was 19.6 Mt CO<sub>2</sub>-e, giving net emissions from the land use, land use change and forestry sector of 33.7 Mt CO<sub>2</sub>-e, or 6% of 2005 emissions. The major greenhouse gas emitted is carbon dioxide, representing 74% of the total national emissions, followed by methane (20%) and nitrous oxide (4%). Eighty-six per cent of Australia's carbon dioxide emissions originate from fossil fuel combustion, extraction and distribution activities, while 85% and 60% of Australia's nitrous oxide and methane emissions, respectively, originate from agriculture (AGO 2007a).

Emissions from most sectors increased between 1990 and 2005, particularly from stationary energy which increased by 43% (Table 1). However, Australia's net emissions have increased by only 2.2% in this period, largely because of a sharp reduction in land clearing in Queensland and NSW, which has decreased LULUCF sector emissions by 74%, offsetting the increase in emissions from the energy and transport sectors (Figure 2 and Figure 3). As a result of this offset, it is currently predicted that Australia's net emissions in the 2008–2012 first commitment period under the Kyoto Protocol will be 109% of 1990 emissions, just above the 108% target (AGO 2006a). The offset due to reduction in land clearing is a 'one-off' mitigation measure – there is very limited capacity to further reduce land clearing emissions. As a result, Australia's net emissions are likely to increase rapidly in the next decade, presenting a major challenge for policy-makers.

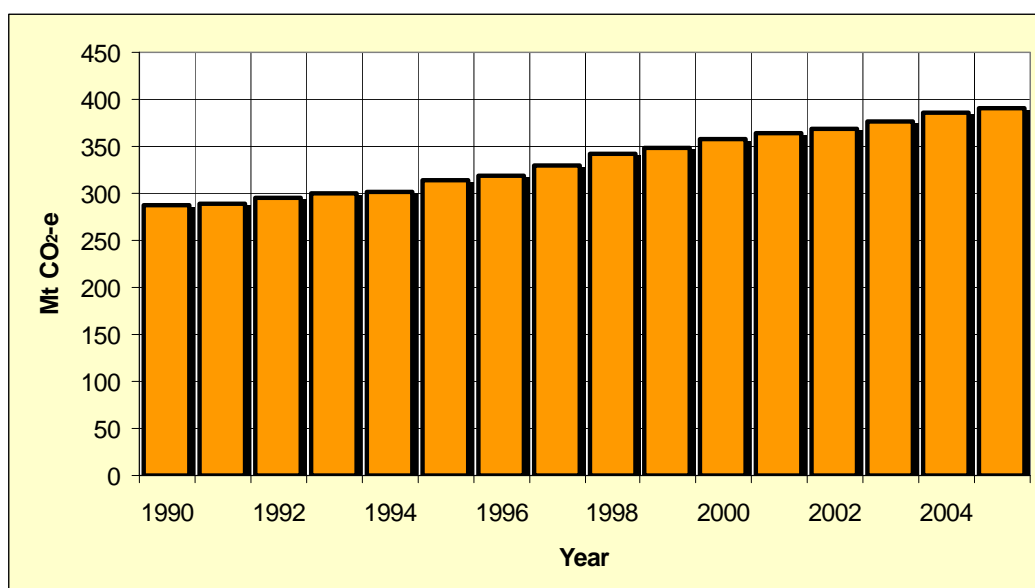
**Table 1. Australia's greenhouse gas emissions by sector (changes since 1990) (Source: AGO, 2007a).**

	Emissions Mt CO <sub>2</sub> -e		Per cent change in emissions
	1990	2005	1990–2005
<b>Australia's net emissions</b>	<b>547.1</b>	<b>559.1</b>	<b>2.2</b>
<b>Energy</b>	<b>287</b>	<b>391</b>	<b>36.3</b>
Stationary energy	196	279.4	42.6
Transport	61.9	80.4	29.9
Fugitive emissions	29.1	31.2	7.3
<b>Industrial processes</b>	<b>25.3</b>	<b>29.5</b>	<b>16.5</b>
<b>Agriculture</b>	<b>87.7</b>	<b>87.9</b>	<b>0.2</b>
<b>Land use, land use change and forestry</b>	<b>128.9</b>	<b>33.7</b>	<b>-73.9</b>
<b>Waste</b>	<b>18.3</b>	<b>17</b>	<b>-6.9</b>



**Figure 2. Trend in greenhouse gas emissions from the land use, land use change and forestry sector, Kyoto Accounting method<sup>2</sup> (source: AGO 2007a).**

<sup>2</sup> Methods for calculation of the National Greenhouse Gas Inventory vary from those used to report compliance with the commitments under the Kyoto Protocol.



**Figure 3. Trend in greenhouse gas emissions for the energy sector, Kyoto Accounting (source: AGO 2007a).**

### 3.2 NSW EMISSIONS PROFILE

The emissions profile for NSW is similar to the national profile (Table 2). The stationary energy sector makes the highest contribution, due to the heavy reliance on coal for electricity generation. Agriculture contributed 12% of total NSW emissions in 2005.

Livestock emissions were 14.5 Mt CO<sub>2</sub>-e, representing 78% of the Agriculture sector's emissions and 9% of total NSW emissions. The other agriculture subsectors contributed 4.0 Mt CO<sub>2</sub>-e in 2004, including 3.7 Mt from agricultural soils and 0.2 Mt from rice cultivation.

Net emissions in 2004 were 1% lower than 1990 emissions, despite a 24% increase in emissions from fuel combustion. Emissions from the agriculture sector were 20% lower in 2005 than in 1990, largely as a result of the 2002–2003 drought, which led to reduced sheep populations and a reduction in the area of cultivated rice, which also contributed marginally to the reduced emissions. Emissions from manure management increased by 41%, which parallels the increased cattle population over that period; however, the total increase attributed to manure management was only 0.3 Mt, similar to the absolute decrease from rice cultivation.

Emissions due to deforestation declined by 54% between 1990 and 2005.

**Table 2. Emissions profile for NSW (Mt) (AGO 2007d).**

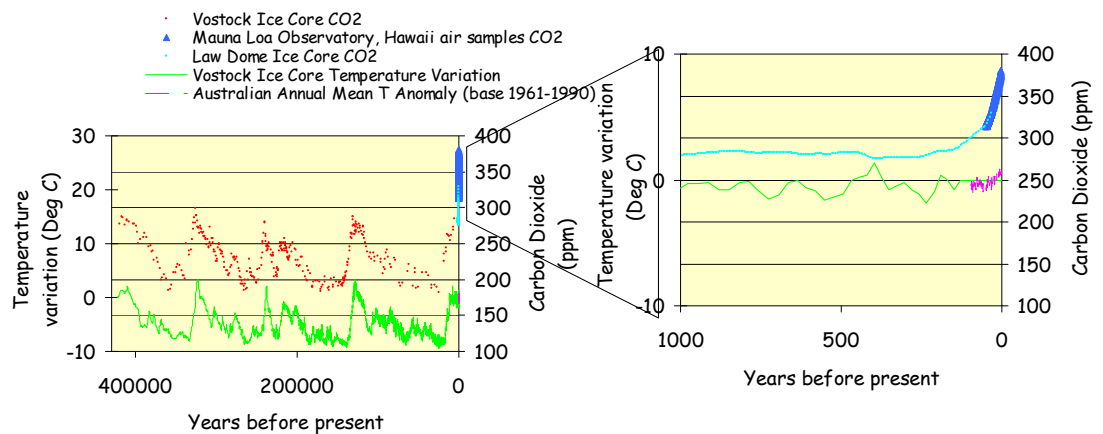
	1990	2005	Trend (%)
<b>TOTAL</b>	<b>159.8</b>	<b>158.2</b>	<b>-1.0</b>
<b>ENERGY SECTOR</b>	<b>94.4</b>	<b>111.8</b>	<b>18.4</b>
Stationary energy	60.5	76.0	25.6
Energy industries	47.8	61.8	29.3
Electricity generation	44.0	57.8	31.4
Other energy industries	2.3	2.4	4.3
Manufacturing and construction	9.0	9.6	6.7
Other sectors	3.5	4.4	25.7
Transport	18.4	21.6	17.4
Fugitive fuels	15.5	14.2	-8.4
<b>INDUSTRIAL PROCESSES</b>	<b>13.8</b>	<b>13.1</b>	<b>-5.1</b>
<b>AGRICULTURE</b>	<b>23.1</b>	<b>18.6</b>	<b>-19.5</b>
Livestock	18.6	14.5	-22.0
Other agriculture	4.5	4.0	-11.1
<b>LAND USE, LAND USE CHANGE AND FORESTRY</b>	<b>22.6</b>	<b>8.8</b>	<b>-61.1</b>
Afforestation and reforestation	0.0	-1.6	
Land use change (deforestation)	22.6	10.4	-54.0
<b>WASTE</b>	<b>5.8</b>	<b>6.0</b>	<b>3.4</b>

## 4 MEASURING CLIMATE CHANGE

Climate change affects the average of a particular variable (e.g. temperature, rainfall, evaporation, wind speed) through changes in the extremes and/or return frequencies the variable normally exhibits. Techniques such as ice core sampling have provided a rigorous dataset which allows measurement of these changes, particularly with respect to temperature and atmospheric composition.

Conclusive scientific evidence now shows that the Earth's climate is rapidly changing, predominantly as a result of increases in greenhouse gases caused by human activity (Stern 2006), particularly since the industrial revolution.

Changes in the concentration of greenhouse gases in the atmosphere have been measured directly over the last 50 years, and can be inferred for the last 420 000 years, through the sampling of ice cores from locations around the globe (Figure 4). The atmospheric CO<sub>2</sub> concentration recorded at the Mauna Loa observatory in Hawaii has increased by 19.4% over the past 5 decades, from 316 ppm of dry air in 1959 to 378 ppm in 2004. This rapid increase is unprecedented when compared with historic carbon dioxide concentrations determined from ice core samples (Keeling & Whorf 2005).



**Figure 4. Temperature and carbon dioxide concentration data from various sources: Vostock Ice Core temperature and carbon dioxide concentration (Petit et al. 1999); Law Dome Ice Core carbon dioxide concentration (Etheridge et al. 1998); Mauna Loa Observatory, Hawaii atmospheric carbon dioxide (Keeling & Whorf 2005); Australian annual mean temperature variation (BoM 2003).**

Increased global temperatures have also been measured directly, from meteorological records, and indirectly, using ice cores (Figure 4). Globally, the Earth's surface has warmed by about 0.7°C since the early 1900s (Stern 2006). This global mean temperature anomaly, which is the difference between the average global mean temperature in the period 1961–1990 and the annual aggregate, is used as a rough index of the scale of climate change. Global mean temperature is averaged over space (globally across the land-surface air and up to about 1.5 m above the ground, and sea-surface temperature to around 1 m depth) and time (an annual mean over a defined time period) (Stern 2006).

In Australia, mean temperatures have increased by about 0.9°C since 1910. In 2005, the Australian annual mean temperature anomaly (compared with the 1961–1990 average) was greater than +1°C, and in 2006 it was +0.47°C (BoM 2007c). The annual mean temperature anomaly for 2005 was the warmest on record, while 2006 had the 11<sup>th</sup> warmest; however, spring in 2006 was Australia's warmest spring on record, at +1.42°C.

Measuring changes in rainfall resulting from changes to atmospheric composition is more difficult than measuring changes in temperature. The difficulty arises from the much greater complexity in the way precipitation is driven by the atmospheric and oceanic circulations and processes. This complexity results in the naturally variable patterns of rainfall that are experienced, particularly in Australia. Compared with other major agricultural exporting countries, Australia has the highest coefficient of variation in annual precipitation at 17%, with Russia the lowest at ~5%. In Australia, variation in crop yield and livestock production from year to year is largely a result of this variation in rainfall (Podbury et al. 1998); therefore, Australian agriculture is very vulnerable to increased variability and shifts in precipitation patterns.

A shift in precipitation has been observed in south-western Western Australia, with winter rainfall declining by 15% since the mid 1970s (IOCI 2002). The underlying cause of this change is not yet certain. Recent observations of a similar shift across NSW at the start of this century are cause for concern. The state average has returned to the averages experienced in the dry first half of last century, 20% lower than the average rainfall received in the second half of last century (See section 7).