Chapter 11

Climate change

Greenhouse gases, including carbon dioxide and methane, are a natural component of the atmosphere, and are released and absorbed through the biosphere and oceans.

Chapter 11

Contents

11.1 INTRODUCTION

Greenhouse gases, including carbon dioxide and methane, are a natural component of the atmosphere, and are released and absorbed through the biosphere and oceans. An overwhelming body of scientific evidence has shown, however, that levels of greenhouse gas in the atmosphere are rising. This rise has primarily been linked to increased emissions due to human-economic activity, driven by demand for energy, goods and services, and to the conversion of natural ecosystems to intensive land use.

The fifth assessment report of the Intergovernmental Panel for Climate Change (IPCC) states that it is extremely likely that increased levels of greenhouse gas emissions from human activity are the predominant cause of the warming of the earth's climate system which has been observed since the mid-20th century. Planetary warming has in turn led to unprecedented changes in the climate system, including both more frequent and intense weather events, and greater climate variability (IPCC 2013) (Box 11.1). These changes are evidenced as increases in the average global temperature (with the past decade being the hottest on record), rises in the average global sea level, changes in average rainfall patterns (with some regions experiencing higher rainfall (e.g. Northern

Europe) and other areas experiencing drying (e.g. the Sahel and southern Africa), increased frequency of heavy rainfall and extreme weather events over most land areas, and more intense and longer droughts (DEA 2011).

Projections show that the planet will continue to warm during the 21st century and that further changes to the climate system will continue to be observed, with the extent of changes depending on the global trends in greenhouse gas emissions (IPCC 2013).

In the 2006 SAEO climate change was considered along with air quality and stratospheric ozone depletion in the chapter 'Atmosphere'. The chapter considered historical trends in concentrations of greenhouse gas emissions, and trends in South Africa's greenhouse gas emissions. Projections of future temperature and rainfall, and potential impacts of climate change on health, water resources, rangelands, maize, forestry and biodiversity were discussed. South Africa's response to climate change was presented.

Since the 2006 SAEO, local and global research has advanced its understanding of the projected impacts of climate change and the associated adaptation needs, as well as the extent of the mitigation challenge. The climate change agenda has risen substantially in global and national importance and the topic has thus been given a dedicated chapter in this 2nd SAEO report.

In reading this chapter, it needs to be borne in mind that climate change is a cross-cutting issue, and thus considerations of climate change are presented in a number of other chapters of this report, namely Chapter 5: Human Settlements, Chapter 6: Land, Chapter 7: Biodiversity and Ecosystem Health, Chapter 8: Inland Water, Chapter 9: Oceans and Coasts, Chapter 10: Air Quality and Chapter 12: Energy.

Box 11. 1: What is climate change and what is causing it?

Radiation from the sun heats the earth's surface. As the surface is heated it gives off radiation to the atmosphere and space, some of which (infra-red radiation) is absorbed and held in the earth's atmosphere by greenhouse gases. Greenhouse gases are trace gases comprising much less than 1% of the atmosphere, and they arise from both natural processes and human-based activities. The warming effect of trace gas greenhouse gas is enhanced by the effect of water vapour, which also absorbs infra-red radiation, leading to an important natural feedback effect between anthropogenic greenhouse gas and water vapour (Figure 11.1). A certain level of greenhouse gas is necessary for human life otherwise the planet would be an estimated 33°C cooler and uninhabitable. However, a rise in concentration of these gases, as is currently occurring as a result of human activities, causes more heat to be retained in the atmosphere, causing the 'enhanced greenhouse effect'.

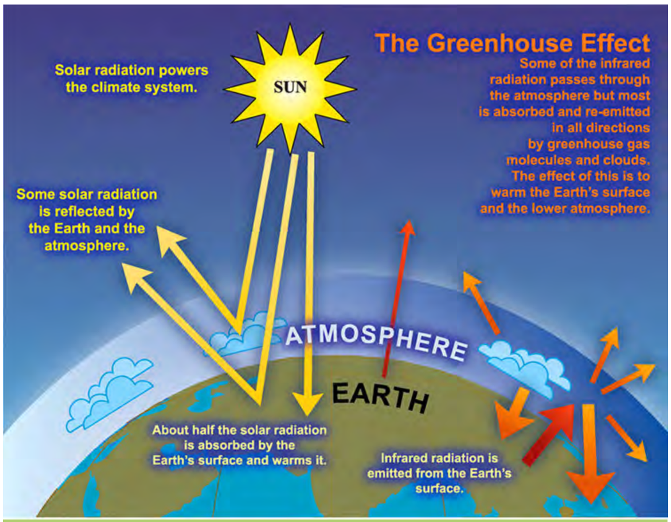


Figure 11. 1: Simplified model of the natural greenhouse effect
Source: IPCC (2007a)

The enhanced greenhouse effect gives rise to an increase in mean global temperatures and already observed and future long-term projected impacts include increases in global average air and ocean temperatures, changes in rainfall patterns, melting of snow and ice, rising global mean sea level, and changes in ocean salinity and altered wind patterns. The changes may also include increased frequency of extreme weather events such as droughts, heavy rainfall events, heat waves and increased intensity of tropical cyclones. Together these outcomes are known as climate change. Both changes in the average climate, and an increase in the number and intensity of extreme weather events, will impact negatively on peoples' lives due to the effects on physical safety, food security, water availability and other factors. Geographical regions will be affected in different ways at different times and to varying extents.

It is important to understand that climate changes (changes in the long term, and average climate) are experienced as a cumulative effect of changes in daily weather, which is observed on a much shorter (daily) basis.

The six greenhouse gases covered by the UNFCCC and its Kyoto Protocol responsible for climate change impacts are:

- Carbon dioxide (CO_2) – released primarily from burning fossil fuels, industrial processes and changes in land use, and which is absorbed by plants and the ocean;
- Methane (CH_4) – primarily from agriculture and degradation of organic wastes;
- Nitrous oxide (N_2O) – from agriculture and industrial processes;
- Perfluorocarbons (PFCs) - used as replacements for ozone-depleting substances;
- Hydrofluorocarbons (HFCs) - used as replacements for ozone-depleting substances; and,
- Sulphur hexafluoride (SF_6) - used in some industrial processes and in electric equipment.

11.2 ANTHROPOGENIC EMISSIONS OF GREENHOUSE GASES

The global level of the most prominent greenhouse gas in the atmosphere, carbon dioxide, increased from pre-industrial concentrations of 280 parts per million (ppm) to about 389 ppm in September 2011 (Figure 11.2). Current levels are higher than at any time during the past 650,000 years (ESRL 2011; Forster *et al*. 2007; IPCC 2011).

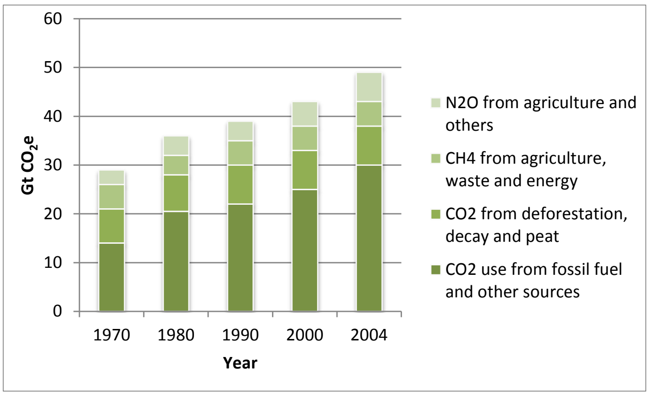


Figure 11. 2: Global annual emissions of anthropogenic greenhouse gases from 1970 to 2004
Source: IPCC (2007b)

Greenhouse gas emissions in South Africa grew from 347.4 Mt carbon dioxide equivalents (CO_2e) (without land use, land use change and forestry - LULUCF) in 1990 to 461.2 Mt CO_2e (without LULUCF) in 2000. This growth was predominantly due to increases in fuel and energy use, which is in line with global trends (DEA 2011). Refer to Chapter 10: Air Quality for more information on emissions.

In South Africa, energy demands associated with economic growth, the growing middle class and the country's energy-intensive mining and minerals processing and manufacturing industries, coupled with emissions from our intensive coal-based electricity supply, are all factors that contribute to the growth in emissions (DEA 2011).

11.2.1 Overall emission trends

The latest published national greenhouse gas inventory for South Africa, which quantifies the sources and sinks of emissions, was conducted for the year 2000 (DEAT 2009a). Observations presented here are based primarily on that inventory.

It is noted that South Africa is in the process of finalizing the fourth national greenhouse gas inventory which will cover the period 2000 to 2010. It is anticipated that this inventory will be ready for publication early 2014. The greenhouse gas inventory compilation process continues to face a number of challenges which include the lack of activity data for the accounting of emissions. To respond to these challenges, South Africa is currently in the process of developed an online national atmospheric emissions inventory system known as the SAAQIS Phase II. The main objective of the SAAQIS Phase II is to ensure that all forms of greenhouse gas data and assumptions are reported accurately, updated and archived following the appropriate international guidelines which are the IPCC. To support the implementation of SAAQIS, South Africa is currently in the process of creating a national system that will manage and simplify its climate change obligations to the UNFCCC process. This process will ensure that the country prepares and manages data collection and all relevant information related to climate change in the most consistent, transparent and accurate manner for both internal and external reporting. This national system will be based on the 'Single National Entity' concept, and will be managed by the DEA. The SAAQIS Phase II will play a major role in managing reporting and processing of data.

The total emissions in 2000, excluding LULUCF, were reported to be 461.2 Mt CO_2e, an increase from 379.8 Mt CO_2e in 1994. LULUCF emissions in 2000 were 442.4 Mt CO_2e, up from 361.2 Mt CO_2e in 1994.

Based on the preliminary results from 2000 to 2010 national greenhouse gas emissions that is to be published in early 2014, the total greenhouse gas emission (excluding LULUCF) in South Africa for 2010 were estimated to be 582.4 Mt CO_2e. This shows an increase of emissions of just over 20 per cent since 2000.

11.2.2 Emissions by greenhouse gas

The Greenhouse Gas Inventory provides a breakdown of emissions for each greenhouse gas. Of the priority emitted gases identified in the Kyoto Protocol, the three most significant in terms of volume are carbon dioxide, methane and nitrous oxide. Table 11.1 shows the emissions of each of the gases reported in the 1994 and 2000 inventories, expressed as CO_2e and the contribution of tetrafluoromethane (CF_4) and perfluoroethane (C_xF_y) in 2000, gases emitted in relatively low volumes but with high Global Warming Potentials (GWP). The figures exclude the uptake of carbon dioxide associated with the LULUCF emissions category.

Table 11. 1: Greenhouse gas emissions trends and percentage change from 1994 to 2000

Greenhouse gas emissions Mt CO_2e	1994 Mt	% of total	2000 Mt	% of total	% change from 1994 to 2000
CO_2	316.0	83.2	362.1	78.5	14.6
CH_4	43,207.0	11.4	75.1	16.3	73.7
N_2O	20,678.0	5.4	21.8	4.7	5.6
CF_4	Not estimated	-	2.0	0.4	-
C_2F_6	Not estimated	-	0.248	0.05	-
TOTAL CO_2e Mt (without LULUCF)	**379.8**	**100.0**	**461.2**	**100**	**21.4**

Source: DEAT (2009b)

11.2.3 Emissions by sector

South Africa's total emissions in 2000 were estimated to be 461.2 Mt CO_2e (461 million tonnes CO_2e). Eighty-three per cent of total emissions are attributable to energy supply and consumption which includes electricity, transport and other fuels (381 Mt CO_2e), seven per cent to direct emissions from industrial processes (32.1 Mt CO_2e), five per cent to agriculture (38.7 Mt CO_2e), and two per cent to waste (9.4 Mt CO_2e) (Figure 11.3). These figures exclude emissions or sinks from LULUCF activities within the Agriculture, Forestry and Other Land Use (AFOLU) sector. These AFOLU activities contribute 2.1 Mt CO_2e as a source, but also provide a sink of 20.8 Mt CO_2e to provide a net sink of emissions of 18.7 Mt CO_2e. Total emissions from LULUCF for the 2000 inventory were 442.3 Mt CO_2e. When the Agriculture and LULUCF sectors are combined on the basis of 2006 IPCC guidelines, total net emissions from AFOLU were 20.0 Mt CO_2e.

South Africa's energy intensity is high mainly because the economy is dominated by large scale, energy-intensive primary minerals beneficiation industries and mining industries. Furthermore, there is a heavy reliance on fossil fuels for the generation of electricity and a significant proportion of the liquid fuels consumed in the country. The energy sector is critical to the South African economy, because it accounts for a total of 15 per cent in the GDP. In terms of energy demand South Africa is divided into six sectors namely industry, agriculture, commerce, residential, transport and other sectors. The industrial sector (which includes mining, iron and steel, chemicals, non-ferrous metals, non-metallic minerals, pulp and paper, food and tobacco, and other) is the largest user of energy and electricity in South Africa.

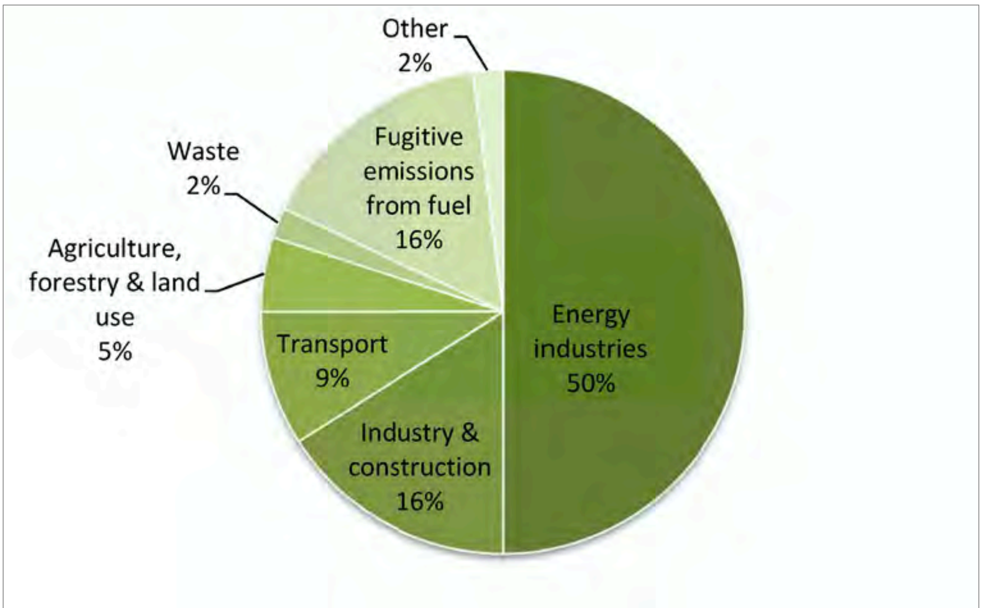


Figure 11. 3: South Africa's greenhouse gas emissions by sector in 2000
Source: DEAT (2009a)

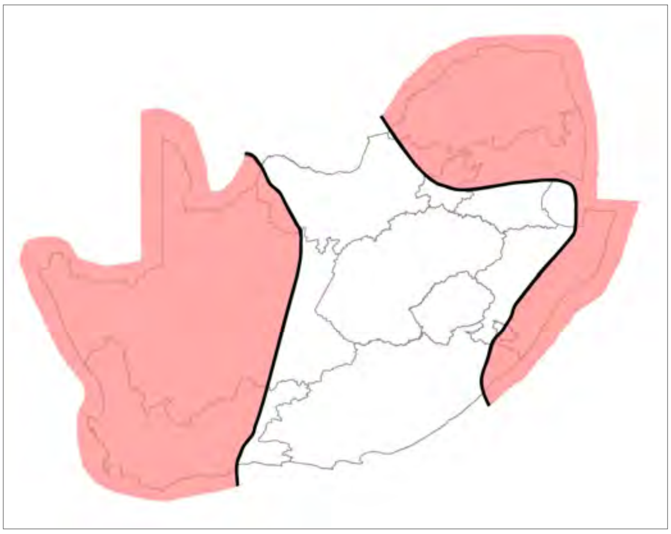
11.3 OBSERVED CHANGES IN CLIMATE

11.3.1 Temperature

South Africa has experienced general warming over the last 40 years (DEAT 2009a; Kruger & Sekele 2012; Kruger *et al.* 2012). The local warming trend in many areas of South Africa is roughly double the mean global temperature trend, which suggests that increased warming has been evident since the latter part of the 20th century (Hansen *et al.* 2001; Lugina *et al.* 2005; Smith & Reynolds 2005).

In general, warm extremes have increased while cold extremes have decreased, with relatively stronger trends in the western, north-eastern and eastern parts of the country (Map 11.1). These observations are in general agreement with previous temperature trend studies for the region, which show a general warming trend, but with weaker trends in the central parts of South Africa (Kruger & Shongwe 2004, New *et al.* 2006).

Differential warming across the country can most likely be attributed to changes in atmospheric circulation over the subcontinent. For example, over the western region changes may include those in the frequency of cold fronts from the west, or weaker impacts of the Atlantic Ocean high-pressure system from the south to south-east, especially during the southern summer.



Map 11. 1: Summary of 2012 recent temperature trend analysis
The shaded areas indicate regions where warming was relatively stronger during the period 1962 to 2009
Source: Kruger and Sekele (2012)

Figure 11.4 shows that the mean temperatures of the past 15 years were all above the 1961 to 1990 average. Although 2011 was the coolest year for the last 11 years (but still above the 1961 to 1990 average). The warming trend indicated by the data from these particular climate stations is still statistically significant at the five percent level (Kruger *et al.* 2012).

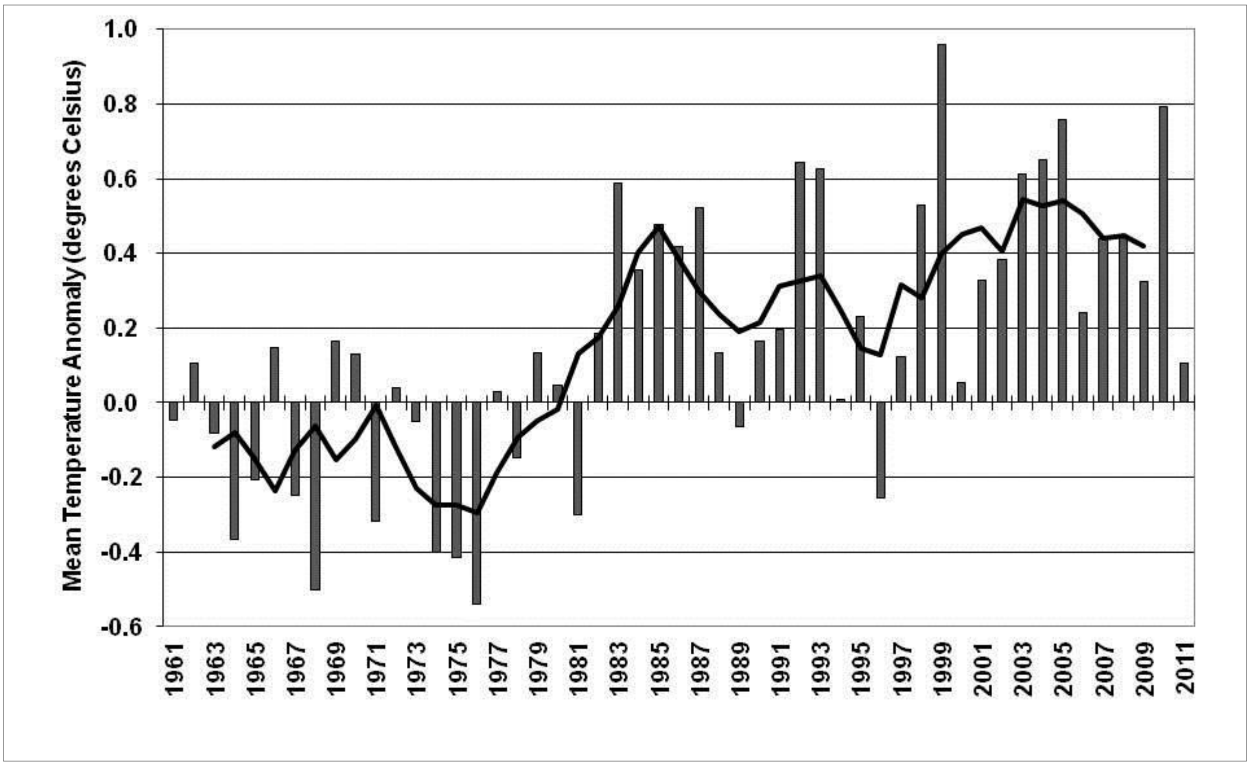


Figure 11. 4: Annual mean temperature anomalies (base period 1961 to 90) of 27 climate stations in South Africa for the period 1961 to 2011
Source: Kruger et al. *(2012)*

11.3.1.1 Rainfall

Some areas showed significant changes in certain characteristics of precipitation between 1910 and 2004 (Kruger 2006). Such localized changes include increases and decreases in annual precipitation, increases in the longest annual dry spell (indicating more extreme dry seasons), increases in the longest annual wet spells (indicating more extreme wet seasons), and increases in high daily precipitation amounts (Box 11.2). In terms of individual rainfall events, it has been suggested that there are parts of the country which have experienced an increased number of days of relatively high or extreme precipitation amounts (Kruger 2006).

Box 11. 2: Observed changes in the oceans

The oceans play a significant role in determining South Africa's climate and weather patterns, in addition to acting as a sink for heat and carbon. Oceans also strongly influence rainfall patterns.
Global warming also impacts on the oceans, with observations to date including:

- **Changes in sea surface temperature:** The Agulhas Current system has warmed significantly by 1.5°C in 20 years. Sea surface temperature decreases (up to 0.5°C per decade) have been observed along the West Coast and near Port Alfred and Nelson Mandela Bay (Port Elizabeth) (Rouault *et al.* 2009, Rouault *et al*. 2010, Rouault *et al.* 2011); and,
- **Sea level rise:** In line with global observations of sea level rise, South African sea levels are also rising (Mather *et al.* 2009). Sea levels along the West Coast have increased by 1.87 mm/a; the South Coast by 1.47 mm/a and the East Coast by 2.74 mm/a.

More details are contained in Chapter 9: Oceans and Coasts.

11.4 HOW IS OUR CLIMATE GOING TO CHANGE IN THE FUTURE?

Located in the subtropics, the southern African region is prone to the occurrence of both droughts and floods, and is thought to be highly vulnerable to anthropogenic-induced climate change (Meadows 2006).

11.4.1 Global projections of greenhouse gas concentrations and climate change

Future climatic states are commonly described through the use of computer simulations of the state of the atmosphere, ocean and land-surface, based on different greenhouse gas emission scenarios. The climate simulations are known as General Circulation Models (GCMs), and are based on the laws of momentum, mass and energy conservation and provide three-dimensional simulations of the state of the atmosphere, ocean and land-surface.

The 4th Assessment Report (AR4) of the IPCC (IPCC 2007b) used scenarios outlined in their Special Report on Emissions Scenarios (SRES) (IPCC 2000) to provide projections of future greenhouse gas emissions. The scenarios differ in terms of assumptions about factors including population growth, economic development, uptake of low carbon technologies etc.

The fifth report from the IPCC, Assessment Report 5 (AR5), will focus more on so-called Representative Concentration Pathway (RCP) projections consistent with one or more of the SRES scenarios in order to simplify the modelled projections. Importantly, the RCP approach is a new approach which does not assume scenarios of global economic development.

Table 11.2 shows expected global atmospheric greenhouse gas concentrations under the IPCC SRES emission scenario families. Further information on what the scenarios mean can be found in the full technical report for this chapter, available online from the DEA website: www.environment.gov.za.

Table 11. 2: Concentration of greenhouse gases in the atmosphere under SRES scenario families

Scenario family name	Likely range of temperature changes (°C) *	Scenario description	Concentration of greenhouse gases (ppm CO_2e)
B1	1.1-2.9	Global convergence on climate change and a move towards a more information- and service-driven economy. Population peaks mid-century and then declines.	600
A1T	1.4-3.8	Rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies, with the drive towards non-fossil energy sources.	700
B2	1.4-3.8	Emphasis on local solutions to economic, social, and environmental sustainability. Increasing global population, intermediate levels of economic development, less rapid and more diverse technological change.	800
A1B	1.7-4.4	As for the non-fossil energy source A1T, but with balance between fossil and non-fossil sources of energy globally.	850
A2	2.0-5.4	Heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Continuously increasing populations.	1,250
A1FI	2.4-6.4	As for A1T although technologies remain fossil and greenhouse gas intensive.	1,550

** Year 2090-2099 relative to 1980 to 1999*
Source: IPCC (2007b)

11.4.1.1 Regional climate modelling (downscaling)

The outputs of GCMs, although not of a low enough resolution to represent changes in regional climate (for example rainfall, wind patterns and temperature of the southern African region), are useful to identify plausible broad-scale changes in the atmosphere and oceans (e.g. shifts in major circulation zones and magnitude of sea level rise). In addition, the spatial resolution of GCMs is too coarse to fully describe certain types of atmospheric circulation systems. Important examples for the southern African region include tropical cyclones (that occasionally make landfall over Mozambique) and mesoscale convective complexes (systems of thunderstorms) that occasionally cause flooding over countries such as Botswana, Zimbabwe and South Africa.

11.4.2 Regional temperature projections

Insight into the plausible range of changes in temperature patterns over Africa and in particular southern Africa, may be obtained from the projections of GCMs (particularly those described in fourth assessment report (AR4) of the IPCC), a number of regional climate modelling studies performed over the southern African region (e.g. Tadross *et al.* 2011) and the projections of GCMs that form part of the Coupled Model Intercomparison Project Phase 5 data base (and that are to contribute to the fifth assessment report (AR5) of the IPCC). These models point towards the following:

- At the continental level, strong warming is anticipated to occur across the continent in all seasons, at a rate of about 1.5 times the global rate of temperature increase. This warming is likely to be greater over the subtropical regions of the continent than over the tropical regions. There is evidence from observations that a strong warming trend has already manifested itself over southern Africa (Kruger & Shongwe 2004; UKMO 2011);
- In South Africa, the increase in air temperatures is likely to be higher over the interior and lower over the coast. Coastal areas are expected to warm by around one degree centigrade and the interior by around three degrees centigrade by mid-century. By the end of the century, warming is likely to be around three degrees centigrade at the coast and five degrees centigrade over the northern interior (DEA 2011; DST 2010). Temperatures over large regions of the interior of southern Africa are projected to rise about twice the global rate of temperature increase. For example, by the time that the global average temperature has increased by two degrees centigrade, temperature increases in the order of four degrees centigrade are projected for the southern African region (e.g. Engelbrecht & Bopape 2011); and,
- Drastic increases in the annual frequency of occurrence of very hot days (defined as days when the maximum temperature exceeds 35 degrees centigrade) are projected. The largest increases in very hot days (increases of more than 100 very hot days per year) are projected to occur over Botswana and Namibia. Relatively small increases in the number of very hot days are also projected over the eastern escarpment areas of South Africa.

11.4.3 Regional rainfall projections

By considering the range of projections of changes in rainfall patterns over southern Africa, as available from the GCM projections described in AR4 of the IPCC (Christensen *et al*. 2007), as well as by considering the specialized regional modelling studies performed for southern Africa (DEA 2011; Engelbrecht *et al*. 2009; Engelbrecht *et al*. 2011; Engelbrecht *et al*. 2012; Hewitson & Crane 2006; Tadross *et al*. 2005; Tadross *et al*. 2011), the following changes seem plausible (although uncertainty of the projections must be acknowledged):

- The southern African region, including South Africa, is projected to become generally drier;
- Most of the summer rainfall region of South Africa is projected to become drier in spring and autumn. However, during summer increased summer rainfall

totals are projected for parts of central and eastern South Africa. As a consequence, slight to moderate increases in annual rainfall totals are plausible over central and south-eastern South Africa; and,
- Significant decreases in rainfall are projected over the south-western Cape in winter.

The projections of regional climate models may also be analysed to obtain insight into potential future changes of extreme weather events (e.g. dry-spell duration, heat waves, heavy falls of rain) over the southern African region. Although research on potential changes in extreme weather events over Africa is currently limited, the regional modelling studies performed over southern Africa provide the following key messages:
- It is plausible that the number of extreme rainfall events resulting from thunderstorms will increase over central and south-eastern South Africa, in response to enhanced anthropogenic forcing;
- It is plausible that the frequency of occurrence of cut-off lows (weather systems that occasionally bring widespread flooding to the South African region) will decrease; and,
- There is inconclusive evidence regarding potential future changes in tropical cyclone tracks and frequencies over the southern African region.

A number of independent studies have indicated the plausibility of South Africa experiencing increases in the frequency of extreme convective rainfall under high levels of greenhouse gases in the atmosphere and hence increased anthropogenic forcing (e.g. Engelbrecht *et al*. 2011; Engelbrecht et al. 2012; Tadross *et al*. 2005), despite the general decrease in precipitation that is projected for this region.

The IPCC pointed out in AR4 that potential changes in the frequency of tropical cyclones over the south-western Indian Ocean have not been investigated rigorously through modelling studies. Recent studies have provided some evidence that a decrease in the frequency of occurrence of cut-off lows (weather systems that occasionally bring widespread flooding to the South African region) will decrease in response to enhanced anthropogenic forcing (Engelbrecht *et al*. 2012). This change is projected to occur in association with the southern displacement of the westerly wind regime, and decreasing rainfall over the south-western Cape.

11.4.4 Regional projections of extreme events

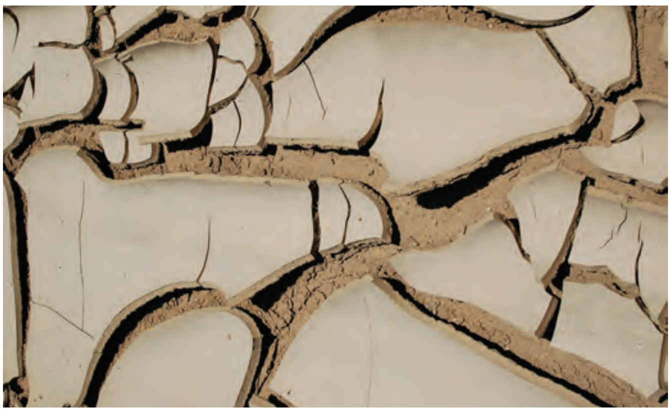
Although research on potential changes in extreme weather events over Africa is currently limited, the regional modelling studies performed over southern Africa provide the following key messages:

"*The increase in extreme events may be at least partially be* (sic) *ascribed to the significant increase in surface temperatures over the region. Such an increase in surface temperature would be conducive to a deepening of the continental heat low, with a subsequent increase in the occurrence of heat convection and convective rainfall. The projected change in the frequency of occurrence of extreme rainfall events is defined as 20 mm of rain falling within 24 hours over an area of 0.5° x 0.5°.*" (Engelbrecht *et al*. 2012).

11.5 DIRECT AND INDIRECT EFFECTS OF CHANGES IN RAINFALL AND TEMPERATURE AND EXTREMES ON THE ENVIRONMENT AND SOCIETY

The projected changes in temperature and rainfall and extremes due to climate change as described above have a number of direct and indirect effects on the biophysical environment, including: decreasing availability of water resources; increased water stress; increased evapotranspiration and decreased soil moisture; increased heat stress on plants, animals and humans; decreased productivity of food crops; changing ecosystems leading to species shifts and extinction; increased alien vegetation; and, increased risk of wild fires. In addition to the impacts on the biophysical environment, climate change is likely to have direct and indirect impacts on society and the economy by affecting food security, human health and livelihoods (Figure 11.5).

A large proportion of South Africa's population is particularly vulnerable to the impacts of climate change due to the fact they already face multiple stresses as a result of a highly variable climate, poverty, inadequate housing and poor access to services, and often their location (Pelser & Redelinghuys 2009). While different communities will experience climate change impacts to different degrees, many communities have low resilience to these stresses, particularly to extreme weather and climate events (e.g. drought and flooding). In addition, livelihoods are often directly tied to the environmental resources which will be stressed in a future climate (e.g. agriculture and fishing). Figure 11.5 summarises some of the key impacts on a number of sectors likely to be seen in South Africa as a function of increased global average annual temperature change relative to 1980 to 1999 (°C).



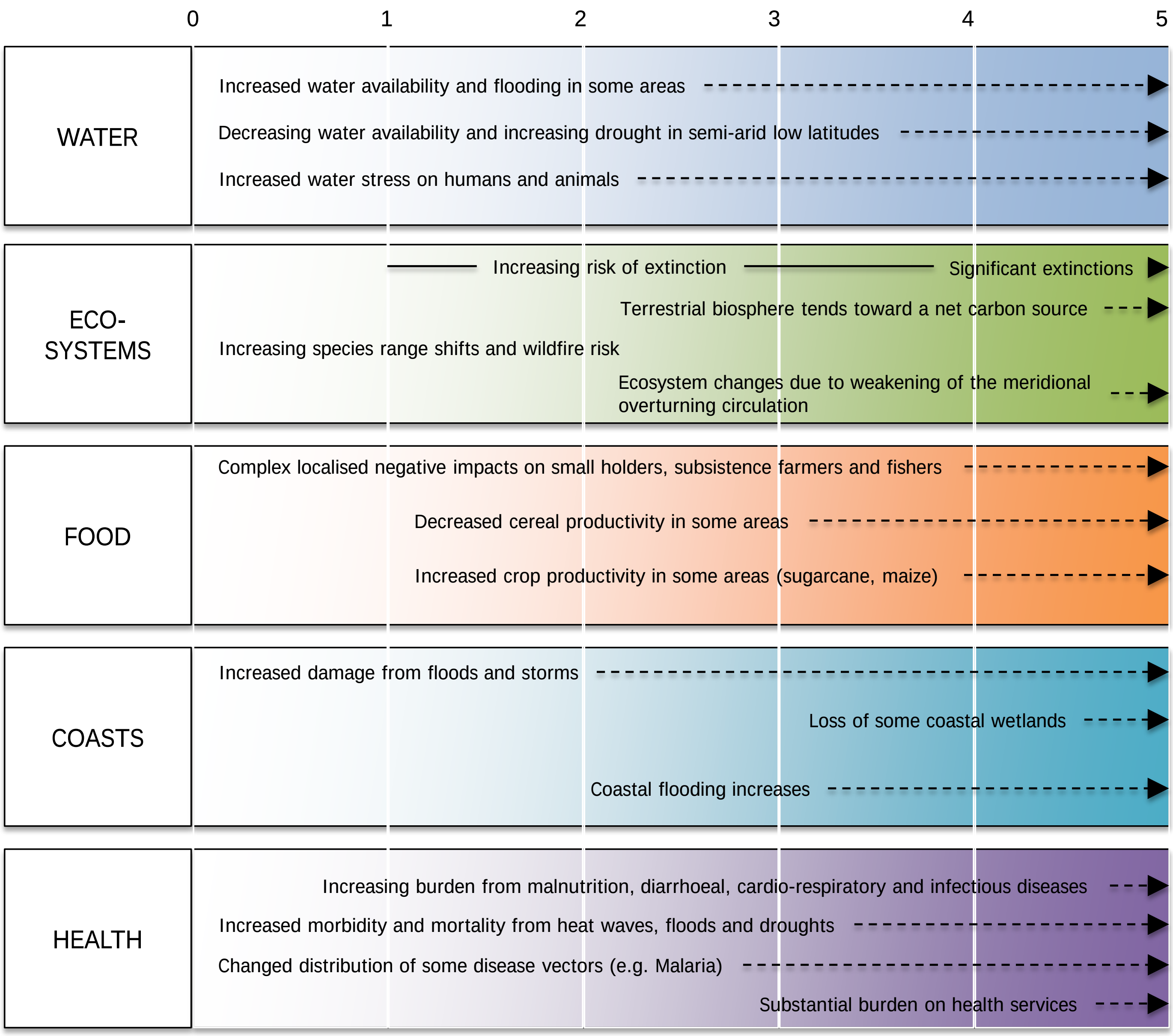


Figure 11. 5: Examples of the projected impacts of an increase in temperature in South Africa
Source: Adapted from IPCC 2007b to show impacts relevant to South Africa

Note that in Figure 11.5 the solid black lines link the different impacts while the broken-line arrows indicate impacts continuing with increasing temperature. The left-hand text indicates the approximate level of warming that is associated with the onset of the impact. It is clear from this figure that many of the impacts start at less than a one degree centigrade rise in temperature. With a two degrees centigrade rise in average global temperature, which is considered to be inevitable given current commitments to mitigation of greenhouse gases, climate change will impact South Africa, and the planet significantly.

The sections that follow unpack the direct and indirect impacts of climate change on a number of key sectors, namely water resources, marine and coastal environments, biodiversity and ecosystem services, crop agriculture and livestock, and forestry. In addition the impacts on human health and livelihoods, infrastructure, and ultimately the economy are explored.

11.5.1 Water resources

Water resources are limited in South Africa, and thus constitute a major constraint to continued economic development and the sustainable livelihoods of people (DEA 2011). Water is arguably the primary medium through which climate change impacts will be felt by people, ecosystems and economies. As a large proportion of South Africa's society is impoverished, they are rendered particularly vulnerable to impacts of climate change.

Chapter 8: Inland Water shows that surface water resources in most of South Africa are already fully utilized (DWAF 2004). Surface water quality in South Africa is variable, with pollution from mining, industry, urbanization, agriculture and power generation evident in many areas.

There is high confidence that changes in hydrological processes such as increased evaporation are linearly related to increasing temperature. Projections of precipitation change and consequent run-off changes are less certain. It is well established in South Africa that surface and groundwater resources will amplify any changes in rainfall (Schulze 2005), as will any intensification or extensification of land use complex interactions between vegetation, soil moisture, and evapotranspiration and water resources (Schulze 2003).

The projected increase in temperature will partially offset any increase in rainfall, due to an increase in potential evaporation of about five per cent per one degree centigrade (Schulze 2010). Combined temperature and precipitation changes will have significant impacts on accumulated streamflows, which is reflected in the projected relative changes in median annual streamflows (by our current understanding, broad increases in the east and decreases in the west) and similar patterns of change in the year-to-year variability of streamflows derived for the intermediate future (2046 to 2065) and more distant future (2081 to 2100) from multiple GCMs (Schulze 2010).

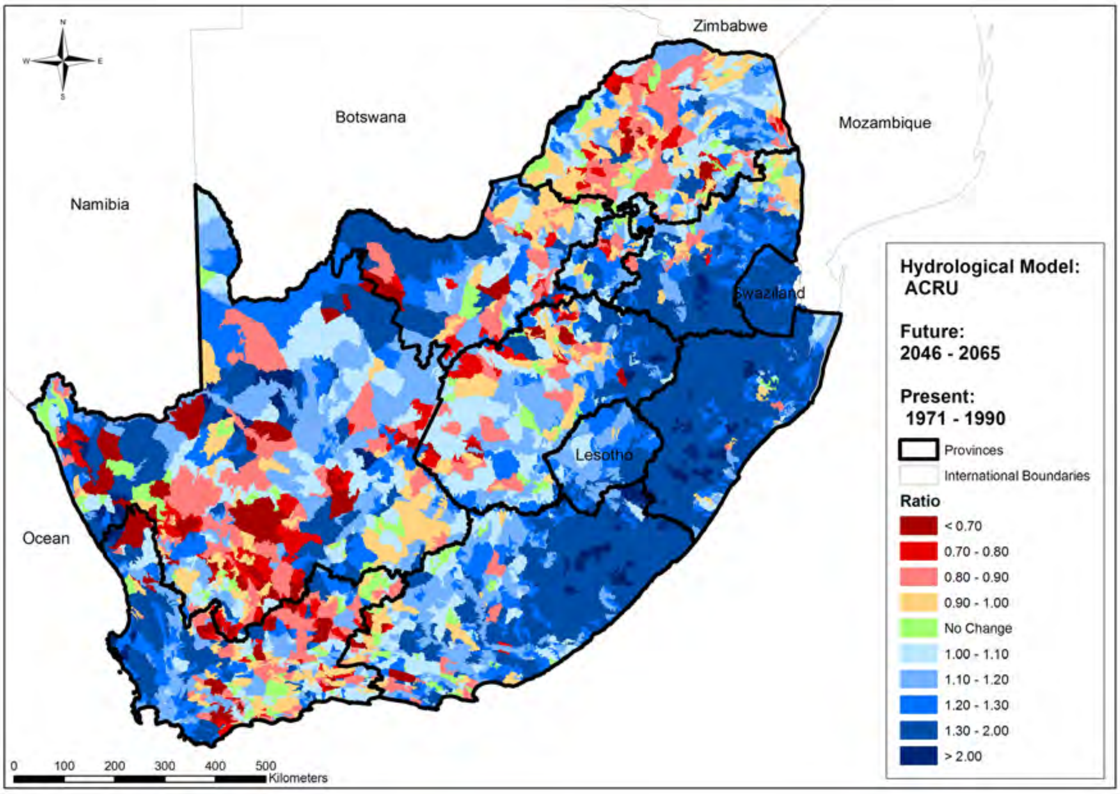
Predicted rainfall changes for the 21st century indicate a wetter East Coast in summer, with drier conditions over the western parts of the country (e.g. Engelbrecht *et al.* 2009; Hewitson & Crane 2006; Hewitson *et al.* 2009; Tadross *et al.* 2006). There is a robust message from both the GCMs and regional climate models for the south-western Cape to receive less winter rainfall in future (e.g. Christensen *et al.* 2007; Engelbrecht *et al.* 2009; Hewitson *et al.* 2009).

The following more localized projections of the direct and indirect impacts of climate change on water resources have been developed, through submitting the outputs of downscaled GCMs via statistical downscaling (note: a method which has projected generally wetting trends in the summer rainfall region) to hydrological models (DEA 2011; Schulze 2010):

- The one-in-ten-year low and high river flows in much of the Eastern Cape and KwaZulu-Natal are both projected to increase by mid-century. This could result in greater water availability in the dry season, but an increased potential for flooding in the wet season, with the consequent negative impacts on water quality and risk management;
- The one-in-ten-year low and high river flows are anticipated to decrease dramatically in the Western Cape and parts of Limpopo, leading to significant impacts related to ensuing water shortages; and,
- Reduced rainfall in the Western Cape, Northern Cape, central interior, and parts of Limpopo may result in reduced recharge to groundwater and falling water levels in boreholes. Where a river's base flow is dependent on groundwater, reductions in flow could be seen when groundwater volumes decrease.

Groundwater recharge to deeper aquifers such as those found in the Karoo and Kalahari is often determined by extreme rainfall events. It is therefore difficult to predict the net effect of climate change on groundwater levels, because even where total rainfall declines, higher recharge of aquifers may be seen if more frequent storms are experienced. Observations and projections over South Africa indicate increases in rainfall magnitude per event (rainfall intensity), independent of overall annual rainfall changes, as well as an increase in the duration of dry spells. Open water evaporation over South Africa is likely to increase by five to ten per cent by 2050, and by 15 to 25 per cent by 2100 due to higher temperatures. Projected future rainfall changes are regionally complex, especially in mountainous areas, which produce much of the country's streamflow. Our understanding is limited significantly by poor coverage of high altitude monitoring stations.

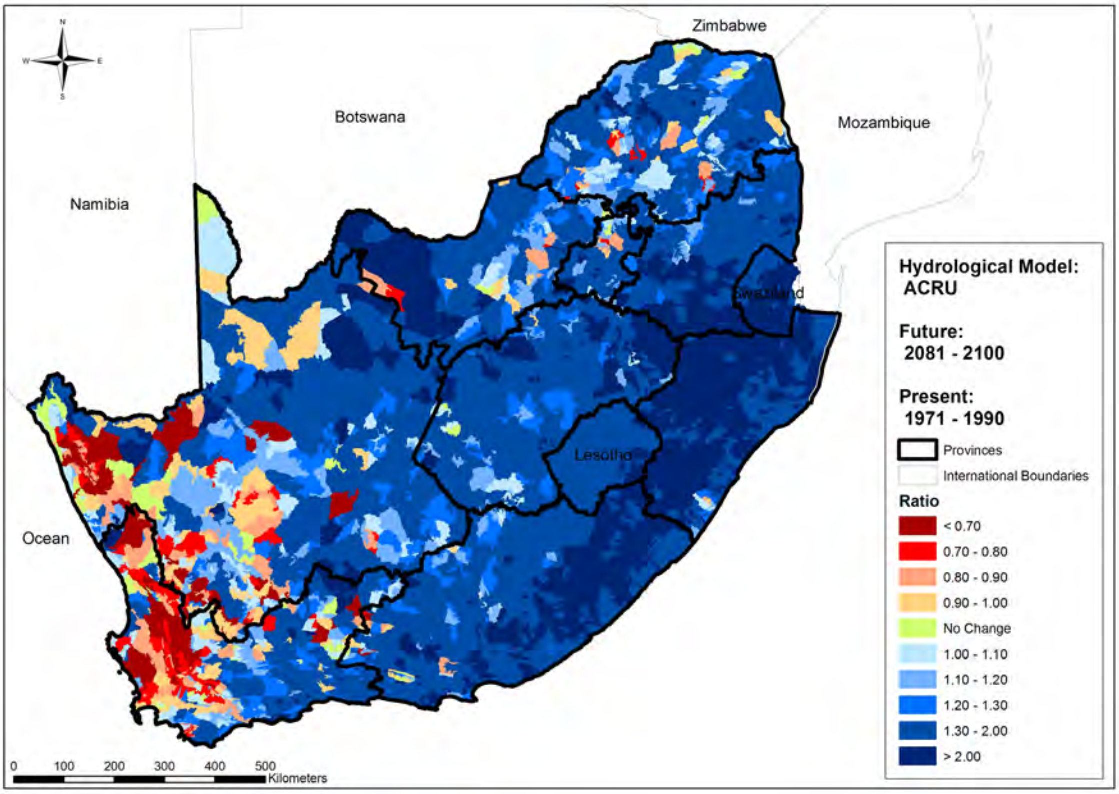
A summary of the projected surface flow changes are illustrated in Map 11.2 and 11.3.



Map 11. 2: Ratio of intermediate future (2046 to 2065) to present (1971 to 1990) mean annual stream flow

Dark blue areas indicate increased intermediate future mean annual stream flow relative to present and dark red areas indicate reduced intermediate future mean annual stream flow relative to present

Source: DST (2010)



Map 11. 3: Ratio of far future (2081 to 2100) to present (1971 to 1990) mean annual stream flow

Dark blue areas indicate increased far future mean annual stream flow relative to present and dark red areas indicate reduced far future mean annual stream flow relative to present

Source: DST (2010)

Future rainfall projections remain challenging because complex rainfall-generating processes such as cloud formation and land-surface-atmosphere interactions are not yet fully understood and resolved in GCMs. Established but incomplete GCM projections for the winter rainfall region consistently suggest future rainfall decreases, while summer rainfall region projections deviate less from present climate. With locally-developed regional downscaling techniques, rainfall projections for the summer rainfall region show a tendency towards wetting (DEA 2011).

Changes in rainfall patterns (both wetting and drying) and extreme rainfall events are also likely to increase erosion. Erosion causes increased sedimentation and turbidity in watercourses which has a negative impact on aquatic ecosystems. Furthermore, increased water temperatures and decreased light penetration (due to increased turbidity) provide favourable conditions for algal blooms. Increased water temperatures may also directly impact aquatic life. Finally, increased salinity of soils is also likely due to increased evaporation (DEA 2011).

11.5.2 Marine and coastal environments

South Africa is rich in marine biodiversity and physical changes in the marine and coastal environment as a result of climate change can have significant impacts on local ecosystems as well as the communities that depend on these resources for their livelihoods. Some of the impacts are listed in Table 11.3.

Table 11. 3: Direct and indirect impacts on marine and coastal environments

Climate change parameter	Direct and indirect impact on marine and coastal environments
Increased storm frequency and intensity, storm surges	• Over 80% of South Africa's coastline is sandy and already susceptible to erosion (Theron & Rossouw 2011). Increased storms and sea surges will likely result in extreme erosion in certain coastal areas resulting in a decline in certain sandy coastal habitats (either directly or as a result of increased sediment levels) as well as damage to coastal infrastructure. • This can further impact on local communities reliant on coastal environments for their livelihoods.
Increased sea temperatures	• Increasing sea temperatures have implications for coastal fish species and other sea life, most notably resulting in shifts in distribution and abundance (James *et al*. 2011). The degree to which species are affected depends on how sensitive their breeding cycles and metabolisms are to temperature, but can lead to species shifts and migration as well as possible extinction of species as their natural habitat changes. • This too can impact on communities whose livelihoods are linked to particular species.
Increased CO_2 concentrations in seawater	• The reduced pH as a result of increased CO_2 levels can have significant impacts on coastal ecosystems. Resulting ocean acidification is likely to particularly negatively affect marine organisms that take up calcium carbonate to create their shells or exoskeletons (Bernard *et al*. 2011).
Sea level rise	• Rising sea levels will put increasing pressure on storm defences and coastal infrastructure such as breakwaters, revetments and sea walls with the consequence that these will require more maintenance and likely have shorter lifespans. • Sea level rise in combination with storm surge during storm events can exacerbate erosion, saltwater intrusion and sedimentation effects impacting ecosystems and fisheries (Theron 2011).

11.5.3 Biodiversity and ecosystem services

Biodiversity and ecosystems are affected by a number of factors, including climate change and changes in land use, atmospheric composition carbon dioxide, nitrogen deposition, climate, and the spread of invasive alien species (Hassan *et al*. 2005, Scholes & Biggs 2004). The potential impacts of climate change on ecosystems and biodiversity therefore need to be assessed in relation to, and in conjunction with, a range of current and future anthropogenic stresses.

It is anticipated that unmitigated anthropogenic climate changes are likely to cause largely adverse impacts on the country's ecosystems and biodiversity. For example, the warming of the bioclimate and related drying projected by climatologists in the late 1990s were used to produce modelled projections that indicated that bioclimatic zones suitable for the country's biomes could be reduced to between 38 per cent and 55 per cent of their current coverage (Kiker 2010). This projection pointed out that this did not imply that all biodiversity would cease to exist in these areas, but that species with vulnerable traits such as low reproductive capacity, and smaller geographic ranges within at least these parts of the biome, would face an increased risk of range reduction or extinction. Geographic range shift modelling of species has provided some further insights and estimates of vulnerability, especially for the winter rainfall biomes (Midgley & Thuiller 2007), using the same family of climatic projections. It has however become clear that bioclimatic modelling methodologies used in these kinds of assessments provide fairly broad indications of risk that require careful interpretation in the context of other approaches (Box 11.3).

Further mechanistic work has subsequently identified the need to consider an understanding of how communities within biomes function, in relation to climate change. In this regard, important work has identified that changing disturbance regime (such as grazing and fire) determine ecosystem structure, and are biome-specific. The ability to model such changes are still developing internationally, but provide some useful further insights into changing biome distributions, and there is a need to build national capacity in these skills through engaging with international groups because they help to predict significant changes in land-cover in response to climate and atmospheric carbon dioxide changes.

Box 11. 3: Project Climate Change impacts on ecosystems

The vulnerability assessment for all South African biomes (DEA 2013a, in prep) provides an ecological understanding of projected climate change impacts on biomes, ecosystems and their species. The study indicates that spatial patterns of change are consistent between the low and high risk scenarios, but that there are significant differences in the extent of projected changes. Refer to Chapter 7: Biodiversity and Ecosystem Health for a map of South Africa's biomes. Some of the key findings are:

- The Grassland biome appears to be one of the biomes most at risk of significant change under all the scenarios. Areas with a climate envelope suitable for Grassland are predicted to be greatly reduced under all scenarios, and in the high risk scenario to persist only in the highest altitude areas;
- The climate envelope found in what is currently the Nama-Karoo, is likely to resemble an arid Savannah under the low risk and intermediate scenarios, and a Desert climate envelope under the high risk scenario;
- The area with a climate envelope suitable for Indian Ocean Coastal Belt increases under the low risk scenario with the warm moist conditions which favour this biome expanding south-westwards along the coast and extending inland. However, as soon as water becomes less available under the intermediate and high risk scenarios, the area with a climate suitable for Indian Ocean Coastal Belt shifts to a Savannah climate envelope;
- The Succulent Karoo will largely persist under all the scenarios. This contrasts with previous predictions from the mid-1990s as newer climate models indicate far smaller impacts on winter rainfall than early models predicted;
- The eastern and northern sections of Fynbos are likely to be under climate stress with the climate envelopes in these areas becoming more like Succulent Karoo or Albany Thicket. The core south-westerly portions of Fynbos (especially the mountainous areas), remain within the current biome envelope, but probably with significant up-slope movement for particular species and habit types;
- Areas with an Albany Thicket climate envelope persist under the low risk scenario and intermediate climate scenarios, but are replaced by Nama-Karoo and Savannah conditions under the high risk scenario. Areas with a climate similar to the current Desert biome are likely to expand in the future into areas which are now Nama-Karoo;
- It is extremely difficult to predict exact distributions of the climate envelope for the small Forest biome, but it is likely that many Forest areas which are generally dependent of consistently available moisture and protection from fire, are likely to be under increasing pressure in the future; and,
- Although the climate envelope suitable for Savannah is likely to expand significantly in the future, and specific Savannah species are likely to benefit, this does not necessarily benefit existing habitats and species assemblages.

Terrestrial ecosystems provide a number of vital services for people and society, such as biodiversity, food, fibre, water resources, carbon sequestration, and recreation. The future capability of ecosystems to provide these services is determined by changes in socio-economic characteristics, land use, biodiversity, atmospheric composition and climate (MA 2005). Several studies have shown that land use changes and climate change poses the greatest threats in history to the realization of sustainable development (MA 2005). To ensure the long-term well-being of the biodiversity, ecosystems and people of southern Africa, it is essential to understand the specific vulnerabilities of the region, biomes and ecosystems to climate change and to define the urgent priority actions needed to ensure that people and biodiversity can adapt to these changes (DEA 2013a).

The Biome Response Measure (2013b, in prep) study explored and proposed different response measures at different biomes, ranging from ecosystems to ecological processes and governance (DEA 2013b). These are:

- Ecosystem security;
- Ecosystem management;
- Enforcement of relevant legislation;
- Development of strategies, policies and plans;
- Monitoring, modelling and research co-ordination;
- Institutional strengthening;
- Citizen engagement;
- Engagement with other sectors presenting key pressures;
- *Ex situ* conservation;
- Translocation of indigenous species; and,
- Linkages to and from related sectors (ecosystem links).

The natural environment provides a number of ecosystem services that may also be disrupted by changes in climate. These services include mitigating the effects of floods, protection from erosion, purifying water, cycling nutrients and decomposing wastes.

A number of the projected impacts of climate change on biodiversity are summarized in Table 11.4.

Table 11. 4: Direct and indirect impacts on biodiversity

Climate change parameters	Direct and indirect impacts
Increased temperatures, altered rainfall patterns and water availability	• These climate parameters can result in spatial shifts in preferred climate conditions or in extreme cases the loss of these 'bioclimates' that support specific ecosystems (Broennimann *et al*. 2006; Erasmus *et al.* 2002; Rutherford *et al*. 2000). • The Grasslands, Fynbos and Succulent Karoo are the ecosystems most at risk (DEA 2011; Myers *et al*. 2000). • Projections indicate eastward range shifts in animal species and declines in plant and animal species richness in the western parts of the country (Erasmus *et al.* 2002; Thuiller *et al.* 2006). • In the same way that indigenous species ranges are affected by climate change, so too are the ranges of invasive aliens. Climate change is likely to give rise to conditions that are favourable for alien growth either driving ecosystem conversion or inhabiting disturbed ecosystems (Richardson *et al.* 2000).
Increased levels of CO_2	• Increased levels of CO_2 affect the processes of photosynthesis and productivity of vegetation with the net effect of change in the structure of vegetation cover, promoting woody biomass growth which is likely to impact the Savannah and Grassland ecosystems of South Africa (Bond & Midgley 2000; Hoffman & Vogel 2008).
Extreme weather events	• Extreme weather events and increases in the frequency and severity of these may also make ecosystems more susceptible to invasion by alien species (Thuiller *et al.* 2007). Increased alien invasive species will in turn put further stress on water resources.
Droughts, longer dry spells, increased average and extreme temperatures	• These climate parameters give rise to favourable conditions for the development and spread of wildfires. Three of the South Africa's six biomes are fire-prone and fire-dependent (Bond *et al.* 2005).

11.5.4 Agricultural crops and livestock

South Africa's agriculture sector, which includes both commercial-scale operations as well as small-scale (or homestead farming) and emerging farming (where small-scale farmers focus on cash crops), is already subject to high risks in terms of high year-to-year rainfall variability and highly arid conditions (Schulze 2011). The effects of climate change and variability in terms of increasing temperatures, heat waves, increased carbon dioxide, changes in rainfall patterns, availability of water resources, droughts and flooding are likely to have both positive and negative, location-specific implications on agricultural crops and livestock due to the sub-national variation and interaction of these parameters and other parallel impacts on ecosystems and biodiversity.

General observations for impacts on agriculture include the following (Schulze 2010):

- Increased crop irrigation requirements due to increased temperature increases and decreased water availability;
- Decreased soil moisture levels as a result in changed run-off patterns and dryland agriculture, although this effect will interplay with uncertain rainfall changes;
- Crops grown on marginal land will have to contend with land degradation and reduced soil productivity; and,
- Crop and livestock production could be adversely affected by changes in the distributions of diseases, pests and insects as a result of changing climate conditions.

Some of the specific projections of the impacts of climate change on crops and livestock resulting from downscaled modelling are shown in Table 11.5.

Table 11. 5: Projected climate change impacts on crop agriculture and livestock

Agricultural product	Impact
Maize	• Maize yields are likely to decline in areas of increased temperatures and decreased rainfall, but these declines in productivity may be offset by increased CO_2 concentrations (Walker & Schulze 2008). • Reduced water availability will reduce the suitability for maize growth in the more western maize producing regions. However, in eastern production areas, maize yields may increase as a result of increased CO_2 levels (DEAT 2004).
Sugarcane	• The latest projections indicate positive dryland sugarcane yield increases of around 5% per degree increase in temperature. Yields are directly proportional to changes in rainfall (decreased yield with decreased rainfall and increased yield with increased rainfall) (Schulze 2010).
Winter rainfall crops	• Winter rainfall crops, mainly found in the Western Cape, are likely to be water stressed in the future. Crops such as wheat, barley and rooibos tea which are reliant on rainfall are particularly likely to suffer, as are those that require cooler conditions or a critical level of chill units or irrigation (ERC 2007). The area available for growing apples could be reduced by up to 28% (Cartwright 2002). • Heat-tolerant fruit species in these regions, e.g. grapes, stone fruit, citrus in cool to warm regions, and indigenous horticultural species such as fynbos and cut flowers could all benefit from increased temperatures (ERC 2007).
Livestock	• Increased temperatures and humidity can stress livestock, decreasing milk production in dairy cattle and even resulting in death. Heat stress is predicted for the northern parts of South Africa in the near term, and extreme heat stress in the north west in the distant future (Nesamvuni *et al.* 2011). • Grazing lands may be reduced due to encroachment of woody biomass and alien species, due mainly to increased CO_2 fertilization effects.

11.5.4.1 Forestry

In 2000, about 25.6 per cent of the country was covered by woodlands/bushlands, 1.4 per cent by plantations, and 0.4 per cent by indigenous forests (van den Berg *et al.* 2008). There is currently net afforestation, as the forestry industry expands. Natural forest areas have been reduced in extent since colonization in the 17th century, but this trend appears to have stabilized, with some local exceptions.

The forestry sector in South Africa is at risk from climate changes. In terms of projected impacts, plantation forestry is likely to decline in the south-west of the country due to drying trends, but wetting trends in other areas of the country may give rise to increased areas suitable for forestry. Overall, it is projected that in the medium and longer term, the total area of potential afforested land will increase due to the wetting trend over the eastern seaboard and adjacent areas.

Current projections of climate change suggest that the area under plantation forestry is likely to remain constant or even extend in the eastern parts of the country and increase slightly in productivity. The frequency and intensity of fires is likely to increase due to an increase in temperature and dry spells caused by a more erratic rainfall, and this will impact negatively on plantation forestry. The forest industry can possibly counter this through a combination of proactive fuel reduction and reactive fire-fighting, but this will increase production costs. Plantation forestry uses more water than natural vegetation, which has led to restrictions on forest plantation expansion. Increased demands on water could translate into further restrictions on plantation forestry, and these will be exacerbated in areas where rainfall is likely to decrease, such as the Western Cape (DEA 2011).

In the case of plantation forestry, should rainfall remain stable, or increase in afforested areas of South Africa, it is unlikely that planted areas will decrease in extent. However, forestry plantations use more water than native vegetation, and depending on the extent of afforestation can significantly reduce the flow in rivers, and this makes them vulnerable as a competitor for scarce water resources (DEA 2011).

A number of studies have attempted to model the potential future impacts of climate change on the extent and productivity of plantation forestry in South Africa (Fairbanks & Scholes 1999; Schulze 1995; Warburton & Schulze 2008). Most of these studies use rainfall and temperature to map areas that are potentially suitable for afforestation with a particular species. These studies have concluded that, in the medium and longer term, the total area of potential afforested land is projected to increase due to the wetting trend over the eastern seaboard and adjacent areas. For specific species, it is projected that the *Acacia mearnsii* potential growing area will move towards the interior from the current near-coastal distribution, while the two other major species (*Eucalyptus grandis* and *Pinus patula)* will lose some of their current growing areas, but gain overall in climatically suitable area and in productivity. In the southwest the drying trend coupled by an increase in temperature of between 1.5 and 2.5°C will culminate in an increase in soil moisture stress in the distant future, which in turn will lead to a reduction in viability of commercial plantations (DEA 2011).

11.5.4.2 Health Impacts

South Africa already faces significant development challenges that impact human health including widespread poverty, malnutrition, inequality, unemployment, service delivery, energy insecurity and high prevalence of tuberculosis (TB) and HIV/AIDS. Health impacts will arise or worsen due to both climate stresses (gradual changes in average climate and climate variability) and climate shocks (extreme weather events). Table 11.6 explores some of these direct and indirect health impacts attributable to climate change.

Table 11. 6: Direct, indirect and longer term impacts on human health as a result of climate change

Direct and indirect impacts	Description
Heat stress from increased temperatures, longer dry spells, heat waves, drought	• Heat stress can cause exhaustion, ill health and mortality, particularly in vulnerable sectors of the population (Bambrick *et al.* 2008).
Damage caused by extreme weather events	• Severe storms, flooding and resulting fires from lightning strikes can result in injuries and mortality as well as disruption to affected communities.
Water borne diseases	• Limited access to clean water and flooding events can both contribute to increased cholera, dysentery and typhoid outbreaks particularly in poor, high-density settlements (Patz 2002).
Malaria	• Increasing extreme rainfall events (causing more standing surface water) and rising temperature has been suggested to potentially favour the spread of malaria, particularly along South Africa's north-east borders, although this has not been observed in recent trends (Thompson *et al.* 2005).
Bilharzia	• Similarly to malaria, increased flooding may favourably impact the distribution of the host snail leading to the spread of bilharzia to previously unaffected areas.

11.5.4.3 Livelihoods

Production and income activities and other livelihood activities are likely to be affected by climate change and variability, particularly as noted in previous sections in rural areas where rainfall affects agriculture and natural resource availability shifts in response to climatic changes. Other factors which will impact livelihoods include food and energy security and the negative impacts of extreme weather events, floods and droughts (DEA 2011). There are currently few studies that provide detailed, consolidated information on the impacts of climate change on urban and rural settlements.

The possibility exists of exacerbation of migration both from rural to urban areas, and of increased refugees from outside of South Africa due to climate change impacts. This could impact further on the environment and the economy (DST 2010; Marchiori *et al*. 2012).

11.5.5 Infrastructure

The increase in frequency and severity of extreme weather events (floods, fires, storms and drought) can cause structural damage to roads, housing, water supply and other infrastructure. Some communities may not have the means to recover from these climate shocks.

A changing climate also requires proactive changes to be made to the built environment to deal with increasing temperatures, and to increase resilience against extreme events. This may range from improving building design to 'climate-proofing' cities and relocation of vulnerable communities (World Bank 2009).

11.5.5.1 Economic costs of climate change

The economic implications of climate change are likely to be substantial, and stretch into the thousands of millions of Rand (DEA 2011). In addition to the direct damage-related costs associated with extreme weather events and climate trends as described previously, indirect costs can be substantial, and have far reaching socio-economic implications. To give a sense of the magnitude of these costs, DEA (2011) have estimated that direct costs of weather-related disasters between 2000 and 2009 (not all of which can necessarily be attributed to climate change) were in the region of R8 billion. Applying a conservative estimate of indirect costs attributed to a disaster being in the order of 15 percent of direct costs, suggests that total cost to the economy is approximately R920 million per annum (2008 values) (DEA 2011). This figure is now reported to exceed R1 billion. With increased frequency of these events, these costs are likely to increase.

Further to the local economic impacts, there are concerns in many sectors that South Africa's global economic competitiveness is at risk due to the emissions intensity of the economy, the associated economic implications of moving towards large-scale roll out of low carbon technologies such as nuclear and renewables, and introducing a carbon pricing mechanism such as a carbon tax into the economy. Industry in particular is concerned about the potential for substantial job losses and shrinkage of carbon intensive sectors of our economy.

Other studies have focussed on the potentially substantial opportunities that can be realized through the green economy. One report estimates that 98,000 new jobs could be created in the short-term and around 255,000 in the medium term, including in energy generation, energy and resource efficiency, emissions and pollution mitigation, and natural resource management (Maia *et al.* 2011). Further economic opportunities relate to energy savings and increased efficiencies resulting from mitigation activities. Globally it has been shown that the cost of inaction on climate change will ultimately be much higher than the cost of early decisive climate mitigation and adaptation actions (Stern 2006).

11.5.6 Summary of the projected provincial impacts of climate change

Table 11.7 provides a summary of some expected impacts of climate change at a provincial level, largely as reported in DEA (2011). This list should not be considered as exhaustive, as some are reported on a geographical rather than a provincial level, and may have been excluded.

Table 11. 7: Summary of the projected provincial impacts of climate change

Province	Projected climate change parameters and impacts	Reference
Eastern Cape	• Increased annual mean temperatures throughout the province of between 1.5 °C and 2.5 °C. • Stable to slightly increased rainfall and with increased intensity. The east of the Province is likely to see rainfall increases. • Vulnerability to sea level rise. • One-in-ten-year low and high river flows are projected to increase by mid-century. Could result in greater water availability in the dry season, but the potential for flooding in the wet season. • Exposure of rural communities to increased flooding and water contamination leading to health impacts. • Sugarcane productivity could increase. • High vulnerability of agriculture to increased temperatures leading to increased evaporation and decreased productivity and/or irrigation requirements and increased likelihood of infestation of pests and diseases. • Potential disruption of fisheries due to increased sea temperatures.	Johnston *et al*. (2011); EC DEDEA (2011); DEA (2011); Schulze (2010); and, Theron & Rossouw (2011).
Free State	• Agriculture could be adversely affected by increased flooding and erosion and/or decreases in water availability. • Exceeding of tolerance thresholds of feedlot cattle to temperatures, humidity, radiation and wind speeds. • Potential mild stress on dairy cattle in the northern Free State.	Nesamvuni *et al.* (2011); and, DEA (2011).
Gauteng	• Increased intensity and variability of rainfall leading to an increased frequency of flash floods. • Decreased water availability due to increased evaporation from dams supplying Gauteng. • Increasing frequency of droughts. • Low-income urban communities vulnerable to lack of food security and adverse health effects due to climate stresses.	GDARD (2011); and, DEA (2011).
KwaZulu-Natal	• One-in-ten year low and high river flows are projected to increase by mid-century. Could result in greater water availability in the dry season, but the potential for flooding in the wet season. • Exposure of rural communities to more flooding and contamination. • Sugarcane productivity could increase. • Potential mild stress on dairy cattle. • Vulnerability to sea level rise and extreme weather events. • High vulnerability of certain agricultural crops due to flooding and increased temperatures.	Nesamvuni *et al.* (2011); DEA (2011); Schulze (2010); and, Theron & Rossouw (2011).
Limpopo	• The one-in-ten year low river flows and one-in-ten year high river flows are anticipated to decrease, leading to significant impacts related to ensuing water shortages. • Decrease in summer rainfall. • Reduced recharge of groundwater. • Flooding, contamination of available water, and drought. • High vulnerability of certain agricultural crops due to decreased water availability and increased temperatures.	Schulze (2010);and, DEA (2011).
Mpumalanga	• Vulnerability of forestry to reduced water availability and fires. • Potential negative impacts on maize production. • Sugarcane productivity could increase. • Agriculture could be adversely affected by increased flooding and erosion and decreases in water availability.	Schulze (2010); DEA (2011); and, DEAT (2004).
North West	• None identified explicitly.	

Province	Projected climate change parameters and impacts	Reference
Northern Cape	• Reduced rainfall leading to reduced groundwater recharge. • Exceeding of tolerance thresholds of feedlot cattle to temperatures, humidity, radiation and wind speeds. • Potential mild stress on dairy cattle. • Sea level rise.	Schulze (2010); and, Nesamvuni *et al.* (2011).
Western Cape	• The one-in-ten year low river flows and one-in-ten year high river flows are anticipated to decrease, leading to winter drying and significant impacts related to ensuing water shortages (although winter drying will be less marked in mountainous regions). • Reduced groundwater recharge. • Weakly perennial rivers may become seasonal. • Negative impacts on estuaries due to decreased water flows. • Winter rainfall crops likely to be water stressed, and decline in production of apples, rooibos and small grains. • Agriculture could be adversely affected by increased flooding and erosion and decreases in water availability. • Vulnerability to sea level rise and extreme weather events resulting in storm surges.	Schulze (2010); DEA (2011); ERC (2007); and, Theron & Rossouw (2011).

11.6 RESPONSES

Responses to climate change in South Africa are considered from two perspectives, the mitigation response (reducing our greenhouse gas emissions) and the adaptation response (related to preparing for the impacts of climate change).

11.6.1 South Africa's climate change mitigation response

11.6.1.1 South Africa's mitigation pledges

The basis for proposing South Africa's contribution to global greenhouse gas mitigation was established through the Long Term Mitigation Scenarios (LTMS) process, which was published in 2007 and adopted by Cabinet (DEAT 2008). The LTMS was the outcome of a multi-stakeholder process to explore various scenarios for mitigation in South Africa, and the contributions of various interventions which could be undertaken to achieve mitigation (Box 11.4).

In 2009, on the eve of the Copenhagen Conference of the Parties (CoP) of the UNFCCC, the President announced that South Africa would implement mitigation actions that would collectively result in a 34 percent and a 42 percent deviation below its 'business as usual' emissions growth trajectory by 2020 and 2025 respectively. The extent to which this outcome can be achieved is predicated on the extent to which developed countries meet their commitment to provide financial, capacity-building, and technology development and transfer support to South Africa. More recently, this deviation off an undefined trajectory has been expressed as a range of absolute numbers in the National Climate Change Response White Paper (NCCRWP) (Figure 11.6) (RSA 2011). Under this trajectory, emissions peak in the period 2020 to 2025 in a range with a lower limit of 398 Mt CO_2e and upper limits of 583 Mt CO_2e and 614 Mt CO_2e for 2020 and 2025 respectively. Emissions then plateau for up to ten years after the peak within the range with a lower limit of 398 Mt CO_2e and upper limit of 614 Mt CO_2e. From 2036 onwards, emissions decline in absolute terms to a range with a lower limit of 212 Mt CO_2e and an upper limit of 428 Mt CO_2e by 2050. Once again, the extent to which trajectory will be achieved depends on support from developed countries.

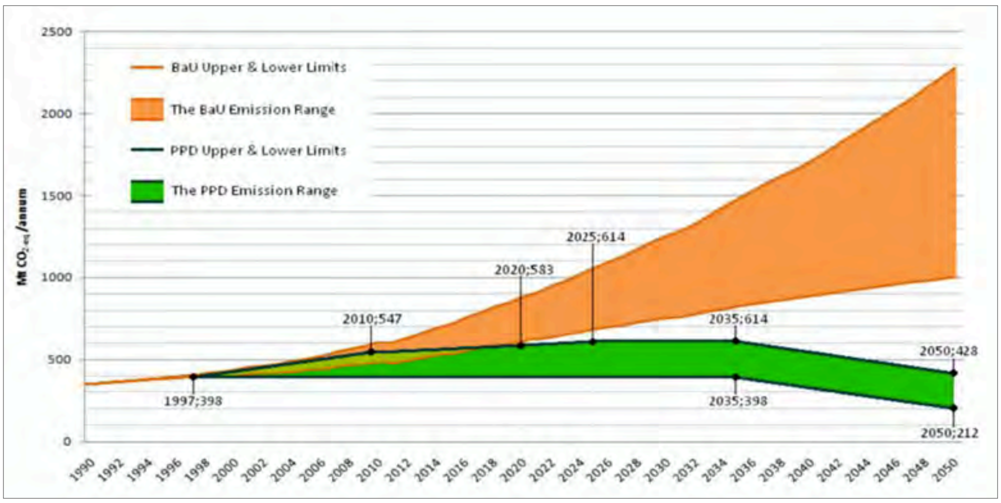


Figure 11. 6: Proposed peak-plateau-decline trajectory for South Africa's emissions
Source: DEA (2011b)

The undertaking to mitigate emissions has been made despite the significant challenge that this presents to the economy, and the fact that mitigation of emissions by South Africa will not avoid the impacts of climate change in the absence of extensive global mitigation efforts. The need to address mitigation in tandem with addressing development challenges is, however, recognized in the White Paper.

In addition to the mitigation commitments described above, climate change is reflected in Output 2 of Government's Delivery Agreement for Outcome 10, which relates to "*reduced greenhouse gas emissions, climate change and improved air/ atmospheric quality.*" Of relevance here are the following:

- **Sub-output 2.1:** Reduction of CO_2 emissions by 34 percent from the 'business as usual' scenario by 2020 and 42 percent by 2025. This output has been articulated in greater detail by the NCCRWP as described above. At present, emissions are still tracking upwards and much effort will be required to achieve this output; and,
- **Sub-output 2.3:** Renewable energy deployment, which will also support mitigation of greenhouse gases, should increase from 2,000 GWh to 10,000 GWh by 2014. In terms of delivery against this target, it is unlikely that this will be achieved, looking at the proposed IRP 2010 build-plan for electricity generation, although some progress is being made given the awarding of the first power purchase agreements to Independent Power Producers (IPP), as discussed below.

Box 11. 4: South Africa's climate change activities in the global context

South Africa continues to play a strong role in the global climate community. South Africa participates in global climate change activities, through being a signatory to the UNFCCC and having ratified the Kyoto Protocol.

The LTMS released in 2007, not only provided a basis for the national mitigation debate, but has also been acknowledged as a world-class analysis (DEAT 2008). Building on the LTMS analysis, South Africa has taken a leading role in the developing world in terms of its conditional pledges made at Copenhagen, its involvement in the BASIC countries' expert group, and issuing of the NCCRWP. The South African team that led the LTMS has received international funding to roll out the analysis globally through a project known as MAPS (Mitigation Action Plans and Scenarios). This project has been launched in five countries in South America.

In 2011, South Africa hosted the CoP17 of the UNFCCC in Durban. The conference provided a platform for negotiations on various climate-related issues including long-term emission reduction targets, as well as for information sharing through lectures, exhibitions etc. One of the main agreements reached at the conference was that all countries globally agreed to implement legally binding emission reduction targets by 2020. The level of reductions is up for negotiation, and will be agreed by 2015 (UNFCCC 2012).

11.6.1.2 South Africa's proposed approach to greenhouse gas emission mitigation

South Africa's overall approach to greenhouse gas mitigation is outlined in the NCCRWP (RSA 2011). It is informed by two contexts, one being its contribution to the international effort to curb global emissions, and the second, management of its development and poverty eradication challenges. Key elements of the overall mitigation approach are shown in Box 11.5. Individual mitigation options with the greatest potential over the medium term (20-years) are suggested to be:

- Shifting to lower carbon electricity generation options (see Chapter 12: Energy);
- Upscaling of energy efficiency applications, especially industrial energy efficiency and energy efficiency in public, commercial and residential buildings and in transport; and,
- Promoting transport related interventions including modal shifts and alternative vehicles and fuels.

Interventions suggested to offer smaller mitigation potential, within the short (5-year) to medium (20-year) period include:

- Carbon capture and storage in the synthetic liquid fuels industry;
- Options for mitigating non-energy emissions in agriculture and land use; and,
- Transitioning the society and economy to more sustainable consumption and production patterns.

In addition to the NCCRWP, various policies, white papers, plans and programmes have been formulated, all of which have the potential to contribute to greenhouse gas emissions mitigation:

- The Energy Efficiency Strategy, released in 2005, which sets a national target for energy efficiency improvement of 12 percent by 2015;
- The Renewable Energy White Paper, which sets a target for renewable energy uptake of 10,000 GWh of energy to be produced from renewable energy sources (mainly from biomass, wind, solar and small-scale hydro) by 2013. A review of the Renewable Energy white paper has been conducted but has not yet been released (DME 2003);
- The Integrated Resource Plan for Electricity 2010-2030, which includes substantial electricity generation from nuclear and renewable energy sources (DoE 2011a);
- The IPP Procurement Programme, otherwise known as REBID, which provides a mechanism for purchasing electricity from independent power producers and thus serves to encourage renewable energy uptake. The Programme seeks to procure a total of 3,725 MW, which is broadly in accordance with the capacity allocated to Renewable Energy generation in the Integrated Resource Plan (IRP) 2010; and,
- The Solar Water Heater Programme, which targets installation of one million solar water heaters in the period 2008 to 2014.

Progress to date on achieving the targets set in these strategies and programmes has been relatively limited. South Africa has negligible installed renewables capacity, although in December 2011 the Minister of Energy announced the awarding of the first round of contracts for procurement of renewable energy from IPPs under the REBID. A total of 1,416

MW from solar PV (632 MW), solar CSP (150 MW) and wind (634 MW) will be built under this round of contracts. The other 2,209 MW is to be allocated in 2012 (DoE 2011b).

Progress on the roll-out of the solar water heater program has been slow, with 30,974 systems having been installed between the start of the programme in November 2008 and the end of December 2010 (DoE 2012). Furthermore, energy efficiency achievements have fallen short of targets.

Box 11. 5: Key elements of South Africa's overall approach to mitigation

- Using the Greenhouse Gas Emissions Trajectory Range as shown in Figure 11.6, against which the combined outcome of all mitigation actions will be measured;
- Defining desired emission reduction outcomes for each significant sector and sub-sector of the economy based on an in-depth assessment of the mitigation potential, best available mitigation options, science, evidence and a full assessment of the costs and benefits. Where appropriate, these desired emission reduction outcomes will be cascaded to individual company or entity level;
- Adopting a carbon budget approach to provide for flexibility and least-cost mechanisms for companies in relevant sectors and/or sub-sectors and, where appropriate, translating carbon budgets into company level desired emission reduction outcomes;
- Requiring companies and economic sectors or sub-sectors for which desired emission reduction outcomes have been established to prepare and submit mitigation plans that set out how they intend to achieve the desired emission reduction outcomes;
- Developing and implementing a mix of different types of mitigation approaches, policies, measures and actions that optimise the mitigation outcomes, as well as job creation and other sustainable developmental benefits. This optimal mix of mitigation actions will be developed to achieve the defined desired emission reduction outcomes for each sector and subsector of the economy by ensuring that actions are specifically tailored to be the best available solutions and other relevant conditions related to the specific sector, sub-sector or organisation concerned;
- Use of a range of economic instruments to support the desired emissions reduction outcomes, including appropriate pricing of carbon and economic incentives, and the possible use of emissions offset or emission reduction trading mechanisms; and,
- A national system of data collection to provide detailed, complete, accurate and up-to-date emissions data in the form of a Greenhouse Gas Inventory and a Monitoring and Evaluation System to support the analysis of the impact of mitigation measures.

Source: RSA (2011)

11.6.1.3 Provincial and local government responses to climate change mitigation challenges

Provincial and local governments have responded to the climate challenge in different ways, with the majority of the activity to date being planning rather than implementation. Selected examples of plans and activities being undertaken in the various provinces and cities are shown in Table 11.8.

Table 11. 8: Mitigation responses at the provincial and local scale

Province	Mitigation responses
Eastern Cape	• The Eastern Cape's Climate Change Response Strategy provides an indicative emissions inventory for the province and proposes mitigation activities (DEDEA 2011).
Free State	• No information found.
Gauteng	• Gauteng has an Integrated Energy Strategy that includes climate change mitigation as one of its central concerns. The province's Climate Change Response Strategy prioritizes mitigation activities in industry, commerce and mining, transport, energy supply, buildings and waste management (GDED 2011; GDARD 2011). • At the local level, the City of Johannesburg has implemented the Rea Vaya bus rapid transit system which is expected to contribute to a modal shift away from private car use, and has planted around 200,000 trees through the Greening Soweto project (City of Johannesburg 2011). Johannesburg has also taken part in the Carbon Disclosure Project's cities report (CDP 2011). Ekurhuleni Metropolitan Municipality has run an energy efficiency awareness campaign among its workers and made energy efficiency improvements to three of its buildings (City of Ekurhuleni 2011). Tshwane Municipality has drafted a Green Building Development By-Law (City of Tshwane undated), promoted the use of renewable energy through solar heaters and is planning for a bus rapid transit system (City of Tshwane 2010).
KwaZulu-Natal	• No provincial climate change strategy was found online. At the local scale activities, in Durban the eThekwini Municipality has established landfill gas extraction with electricity generation facilities at two landfills (eThekwini, undated). The Durban Climate Change Partnership has been established with the involvement of various stakeholders, focussing on both climate mitigation and resilience (eThekwini 2011).

Province	Mitigation responses
Limpopo	• Although no stand-alone provincial climate change strategy or focussed activities were found at the time of writing, the Limpopo Employment, Growth and Development Plan for 2009 to 2014 makes reference to the need to support transition to a green, low carbon economy, and the support of renewable and lower carbon energy technology development and implementation (Limpopo Provincial Government 2009).
Western Cape	• The Western Cape's Climate Change Strategy and Action Plan includes consideration of a set of mitigation actions covering energy, transport, waste and air quality management (DEADP 2008). • The City of Cape Town suggests that it is involved in 50 programme areas relating to climate change, made up of more than 120 mitigation and adaptation projects co-ordinated through their Energy and Climate Change Action Plan. • The City has established the first phase of an integrated rapid transit system, with further phases being under construction (City of Cape Town 2007, City of Cape Town 2012). The City has also been running a Climate Change Think Tank to lead a proactive response to climate change, on both mitigation and adaptation issues (Cartwright *et al*. 2012).

11.6.1.4 Private sector response to the mitigation challenge

The private sector has shown mixed responses to the climate change challenges. Numerous companies have set targets for emission reductions, and report on their greenhouse gas emissions and changes to emissions intensities through both annual reports and the Carbon Disclosure Project (CDP)[1]. Investment is being made into research and development, and implementation, to reduce emissions, both through changing operations and practices, and through carbon capture and sequestration.

Substantial effort is however still required to meet the overall emission reductions required by the national targets. A study, conducted for the CDP by KPMG, provided an analysis of the Johannesburg Stock Exchange Top-100 CDP submissions in 2010. The study recognized that the Top-100 companies have significant potential for contributing towards meeting South Africa's emission pledges, and furthermore identified that there is an upward trend in the number of companies setting emission reduction targets. Having said this, in 2010 these targets still only achieved a fraction of what is required from the Johannesburg Stock Exchange Top-100 in contributing towards meeting the national pledges. One of the biggest challenges facing these companies is the greenhouse gas intensive nature of electricity supply in South Africa (KPMG 2011).

11.6.2 Climate change adaptation

Climate change adaptation is a vast and challenging topic, a complete discussion of which is beyond the SAEO. Furthermore, adaptation is closely linked to development, in that many of the development challenges facing South Africa and the region could be exacerbated by climate change, unless development and adaptation are undertaken in an integrated fashion. It is recognized that early adaptation responses may require investment in the short- and medium- term, but could help to limit the long-term impacts of climate change. Such investment includes new infrastructure, changing agricultural practices, protecting biodiversity, protecting coastlines and improving resilience of rural and urban communities. Addressing food security issues, particularly in the poorer, least developed areas, also represents a substantial challenge.

To provide a high-level understanding of some of the adaptation challenges, some examples of adaptation responses that may be required by South Africa are provided. This is followed by a discussion on some of the activities that are already underway at the provincial and local level in the country.

11.6.2.1 Adaptation responses available to South Africa

A detailed account of the likely adaptation needs to the areas of impact discussed previously is presented in the Second National Communication to the UNFCCC (DEA 2011). Selected examples of the vast range of adaptation responses are presented in Table 11.9.

1 The Carbon Disclosure Project is a voluntary disclosure system to support measurement, disclosure and management of greenhouse gas emissions. Thousands of companies and cities around the world report emissions according to the organisation's guidelines. http://www.cdproject.net

Table 11. 9: Examples of sectoral adaptation responses.

Sector	Examples of adaptation activities
Water resources	• Water demand management. • Water storage infrastructure to buffer projected extremes of future rainfall regimes. • Effective management of groundwater including groundwater recharge schemes. • Water-sensitive urban design which focuses on capturing water within the urban landscape and minimizing pollution, erosion, and disturbance resources. • Incorporation of water resource impact considerations in land use zoning decisions.
Marine and coastal environments	• Sound integrated ecosystem management practices to protect marine and coastal biodiversity, including fisheries. • Allowing undeveloped coastlines to adapt naturally. • Compilation of shoreline management plans. • Design coastal protection/ developments/ structures specifically to compensate for effects of climate change.
Biodiversity and ecosystems	• Implementation of strategies to minimize adverse impacts of climate change on biodiversity. • Focus on ecosystem-based adaptation, or use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. • Policies and legislation to prevent introduction of new alien species and spread of those already in the country.
Intensive agriculture and livestock	• Wide range of different responses for large scale farmers and those related to rural livelihoods. • Building dams, water conservation, flood and drought management in response to water-related challenges. • Improved soil management. • Management of grazing land for livestock and integrated rangeland management. • Overcoming subsistence farmers' constraints such as poor commercialization, poor infrastructure, and low farm productivity. • Science-driven responses. • Diversification of practices and crops.
Forestry	• Fire management. • Tree selection and breeding to be site specific.
Health impacts	• Management of HIV and TB and management of malnutrition to reduce vulnerability. • Intervention strategies to mitigate the effect of cholera outbreaks. • Continued active programmes to reduce malaria infections.
Livelihoods	• As for terrestrial biodiversity, focus on ecosystem-based adaptation (Midgley *et al*. 2012). • Disaster preparedness. • Skills development.

Source: Adapted from DEA (2011)

Due to the diversity of adaptation needs and the fact that these responses are location specific, they need to be actioned by all levels of government (national, provincial, local and community level).

The NCCRWP identifies a number of flagship programmes which are to be implemented with immediate effect. Adaptation related programmes include the Climate Change Response Public Works Flagship Programme, the Water Conservation and Demand Management Flagship Programme and the Adaptation Research Programme. The White Paper further recognizes the need for co-ordinated approaches to adaptation, and detailed adaptation plans are to be developed for a number of key sectors of the economy, these being biodiversity, forestry, water, coastal management, agriculture, health, tourism, land and rural development, local government, fisheries, human settlements, business/ insurance and rolled out to provincial and municipal levels of government (as per Output 2.4 of the Government Delivery Agreements for Outcome 10). These sectoral adaptation plans, which are to be developed by 2012, will be integrated into the following overall sectoral plans (RSA 2011):

- The National Water Resource Strategy, as well as reconciliation strategies for particular catchments and water supply systems;
- The Strategic Plan for South African Agriculture;
- The National Biodiversity Strategy and Action Plan, as well as provincial biodiversity sector plans and local bioregional plans;
- The Department of Health Strategic Plan;
- The Comprehensive Plan for the Development of Sustainable Human Settlements; and,
- National Framework for Disaster Risk Management.

In setting up these adaptation plans, the NCCRWP (RSA 2011) suggests the following:

- A regional approach will be taken where possible, as neighbouring countries will face similar challenges and there is benefit in sharing resources, technologies and taking co-ordinated actions;
- Due to the uncertainties that remain in climate change projections, adaptation strategies must be able to respond to changing information, conditions and priorities;

- Focused monitoring and evaluation systems are required to support adaptation plans; and,
- Recognition of the importance of the local scale in terms of responses of local communities and local governments should be included.

In addition to national activities, South Africa is involved in regional activities which recognize the cross-border nature of the challenge. These include the Regional Climate Change Programme (RCCP 2009), which was established to help southern Africa adapt to climate change across political borders, and a number of climate related activities under SADC.

11.6.2.2 Existing provincial and local adaptation responses

Many of the provinces and cities within South African have already initiated adaptation related activities. Some examples of responses at the provincial and local scale include those shown in Table 11.10 and Box 11.6.

Box 11. 6: The role of education and research in climate mitigation and adaptation

Education, training and research are important components of South Africa's mitigation and adaptation responses to climate change. The scale of action required for mitigation of greenhouse gas emissions, and the extent of action required to adapt to future changes, suggests a need for extensive public action supported by access to clear and relevant information.

In terms of education, various initiatives supported by local, provincial and national government, the private sector and international finance are already underway in South Africa. At a secondary school level, the science basis of climate change is addressed in the physical science curriculum and impacts and vulnerability are addressed in Geography and Social Sciences (DBE 2003). The National Skills Development Strategy for 2011-2015 does not address climate change itself (DHET 2011). However, the Sector Skills Plans for some of the SETA's do recognize the relevance of climate change and include it in skills planning to varying degrees (AgriSETA 2010; PSETA undated; TETA 2011).

Other targeted educational activities include climate and water conservation awareness campaigns, rural and agricultural training and development, industrial energy efficiency programmes and promotion of renewable energy.

The NCCRP recognizes the importance of furthering education and training in the response to climate change, making commitments to (RSA 2011):

- Incorporating climate change into formal education curricula;
- Considering climate change related issues when reviewing the National Skills Development Strategy and within SETA structures, with accompanied reallocation of resources;
- Providing financial incentives for research and study of climate

Table 11. 10: Provincial and local adaptation responses

Province	Responses
Eastern Cape	• The Eastern Cape's Climate Change Response Strategy is development focused, with clear emphasis on aligning development activities with climate change imperatives. Adaptation programmes and communication, education and awareness components are proposed in the Strategy (DEDEA 2011).
Free State	• No information found.
Gauteng	• Gauteng has a Climate Change Response Strategy and Action Plan. The Climate Change Response Strategy prioritizes adaptation actions in water, urban development and infrastructure, and agriculture and food security, along with a number of cross-cutting issues. The strategy also gives consideration to financial issues and options (GDED 2011; GDARD2011).
KwaZulu-Natal	• No provincial climate change strategy was found online, although at the time of writing the province was in the process of developing provincial impact and vulnerability, and coastal vulnerability, studies. • The Durban Climate Change Partnership has been established with the involvement of various stakeholders, focussing on both climate mitigation and resilience (eThekwini 2011).
Limpopo	• No details of provincial-level adaptation activities were found.
Mpumalanga	• The province convened a provincial climate change summit in 2011 (DEDET 2011). A Climate Change Literacy Programme has been developed to increase awareness of climate change in schools and communities. Tree planting programmes have been undertaken in the province (FTFA 2009).
North West	• No provincial climate change strategy for North West is available in the public domain. The Department of Economic Development, Environment, Conservation and Tourism has, however, hosted a provincial climate change summit (DEDECT 2011). Various studies have been conducted on the impacts of climate change on the province, as they relate particularly to agriculture and adaptation.
Northern Cape	• The provincial government of the Northern Cape is developing a climate change response strategy (Lameyer & Nel 2012) and has organized a provincial Climate Change and Green Jobs Summit in 2011 (DENC 2009).

Province	Responses
Western Cape	• The Western Cape's Climate Change Strategy and Action Plan has a focus on adaptation to allow for developmental priorities. Water supply, biodiversity and infrastructural protection receive particular attention. Key proposed outcomes of the action plan are an integrated water management plan, a climate change, weather research and information programme, and a land stewardship and livelihoods programme (DEADP 2008). • The City of Cape Town suggests that it is involved in 50 programme areas relating to climate change, made up of more than 120 mitigation and adaptation projects co-ordinated through their Energy and Climate Change Action Plan. • The City of Cape Town has also been running a Climate Change Think Tank to lead a proactive response to climate change, on both mitigation and adaptation issues (Cartwright *et al*. 2012). It has commissioned studies on the projected impacts of sea level rise on the City (Brundrit & Cartwright 2012).

11.7 CONCLUSION

The impacts of climate change are already being seen in South Africa, and are projected to intensify over the coming decades. These impacts vary across the country, but are projected to include changes to long-term temperature and rainfall patterns. An increase in extreme weather events including floods and droughts is also projected. The projected knock-on impacts of both long-term changes and extreme weather events include those for agriculture, biodiversity and ecosystem services, water, oceans and marine environments, health, livelihoods, employment, access to resources and infrastructure.

In responding to the climate change challenge, a multi-pronged policy approach will be required at the national, provincial and local levels. The adaptation response requires consideration in policy relating to energy, water, poverty alleviation, economic development, environmental protection and others, so as to minimize impacts on the country. At the same time, there is an imperative for the country to take on its share of global effort in reducing its overall greenhouse gas emissions. While the mitigation ambition will be driven by national climate change policy, it will have influence on policy across the sectors, including on those relating to energy, transport, industry, spatial development and others.

Given that the mitigation ambition, extent of the impacts and the consequent need for adaptation are largely determined by global efforts to reduce greenhouse gas emissions, the country would be well placed to continue to engage in the international climate change forums.

The costs associated with addressing the climate change effort are expected to be high, although early and appropriate interventions, particularly surrounding adaptation, can contribute to reducing the overall impact and cost of climate change for the country. At the same time there are substantial opportunities in moving towards a climate resilient and low-emissions economy and society which could be exploited through early action. Once again, early identification and access of such opportunities will maximize the benefit to be gained.

Box 11.7 provides some examples of the gaps and activities that are required to move towards addressing some of these challenges.

Box 11. 7: Analysis of gaps and future needs relating to climate change in South Africa

A number of gaps need to be filled in order to both reduce South Africa's contribution to greenhouse gas emissions, and to adapt to the potential impacts of climate change. Such gaps include those relating to data, education government activity and research.

Data that is available to support climate mitigation planning and activities should be useful, relevant and meaningful, and should provide for ready comparison against internationally used indicators. This chapter has identified that much of the data relating to emissions is out-dated, and more recent data is required to support planning and decision making. The DEA was preparing an updated greenhouse gas inventory at the time of compiling this report which will help to address the issue. The SAAQIS Phase II (released in 2013/14) will be the tool that the DEA uses to compile the greenhouse gas emissions for submission to the UNFCCC.

A reliable and consistent source of land cover mapping data is necessary to be used for land cover change detection. Chapter 6: Land has also identified this is a critical issue. Land cover data should be complemented with a numerical and spatial database for understanding the sink and source potential of different land use categories. Additional research work to support the national sink/source assessment is due to be commissioned by the DEA. Ongoing work is being conducted in developing an agricultural greenhouse gas inventory. Emissions from the forestry sector also need to be determined more accurately. Locally relevant costs of mitigation options would also be useful to support planning and decision making.

The SAWS has identified their own areas of improvement for data gathering and analysis to help address data gaps. These include:

- Strengthening of SAWS' current observation networks, climate database and forecasting systems on all time scales;
- Extending forecasts to decadal time-scales through

ocean-land-atmosphere research and modelling;

- Quantifying changes in the frequency and intensity of major weather systems affecting SA and its impacts;
- Developing sector specific products and partnerships focussing mainly on water resources, food security, health, disaster risk reduction in context of adaptability;
- Provision of high quality climate science to underpin policy; and,
- Strengthening the scientific expertise to contribute internationally

Research has demonstrated that there is a need to ensure education of the public both on climate mitigation and adaptation and that it is continued and expanded. Such educational messages need to be co-ordinated, and appropriately targeted to their audiences.

There is a need for improved alignment of climate change and energy policy, strategies and programmes across government departments to ensure that existing conflicting content is addressed.

Substantial research is required to support deepening the understanding with respect to vulnerabilities to climate change, and for the identification and implementation of suitable adaptation activities in South Africa, including the development of integrated adaptation frameworks that simultaneously provide multiple benefits. The two sectors most likely to be impacted that require study in this context are agriculture and water. Urban areas, which are growing rapidly, will be particularly constrained by existing limited water resources and vulnerabilities of cities to the effects of climate change are not always fully appreciated or understood. This also requires further research.

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