LONG TERM ADAPTATION SCENARIOS

TOGETHER DEVELOPING ADAPTATION RESPONSES FOR FUTURE CLIMATES

SCENARIOS

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz

On behalf of:
Federal Ministry
for the Environment, Nature Conservation,
Building and Nuclear Safety
of the Federal Republic of Germany

SANBI
Biodiversity for Life

Citation:

DEA (Department of Environmental Affairs). 2016. Long Term Adaptation Scenarios for South Africa (ed. Munzhedzi, SM, Khavhagali, VP., Midgley, GM., de Abreu, P., Scorgie, S., Braun, M., Abdul, Z., Pegram, G., Baleta, H. and Seddon-Daines, D). Long-Term Adaptation Scenarios Flagship Research Programme. Pretoria.

LONG-TERM ADAPTATION SCENARIOS
FLAGSHIP RESEARCH PROGRAMME (LTAS)

LONG TERM ADAPTATION SCENARIOS FOR SOUTH AFRICA

LTAS Phase II, Technical Report (no. 7 of 7)

The project is part of the International Climate Initiative (ICI), which is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

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CGE	computable general equilibrium (model)
CMA	catchment management agency
CMS	catchment management strategy
CSA	climate-smart agriculture
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DRDL	Department of Rural Development and Land Reform
DRR	disaster risk reduction
DRRM	disaster risk reduction and management
DWA	Department of Water Affairs
EBA	ecosystem based adaptation
EPWP	Expanded Public Works Programme
EWS	early warning system
GIZ	Gesellschaft für Internationale Zusammenarbeit
GMO	genetically modified organism
IBT	interbasin transfer
IDP	integrated development plan
LIS	level I stabilisations
LTAS	Long Term Adaptation Scenarios Flagship Research Programme
M&E	Monitoring and Evaluation
NDMC	National Disaster Management Centre
NDP	National Development Plan
NRM	natural resources management
PES	payment for ecosystem services
SADC	Southern African Development Community
SANBI	South African National Biodiversity Institute
SAWS	South African Weather Services
SIPS	Strategic Integrated Projects
UCE	unconstrained emissions
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wildlife Foundation

FOREWORD

This report has been developed as a response to the 2011 Climate Change White Paper's proposal to develop long-term climate change adaptation scenarios for South Africa.

The report marks a milestone in the Long Term Adaptation Scenarios Flagship Research Programme (LTAS). Through developing robust adaptation scenarios it provides new insights into considerations important for planning climate change adaptation responses for South Africa at a range of time scales, and tests a set of tools to identify vulnerabilities, opportunities and risks associated with integrated adaptation and development responses. It also highlights trade-offs and pinpoints where systemic adaptation measures may be required and where particular responses may create 'dead-ends' or maladaptation. Integrating adaptation and development responses to optimise cross-sectoral benefits is complex and would benefit from focused efforts to improve the integrated assessment tools required. This report is the first step in this direction for South Africa.

The adaptation scenarios presented here are the result of both extensive analytical work and a process of stakeholder consultation, and are informed by a review of relevant South African climate change policy. All these elements have been important in improving a collective understanding of the integrated impact of climatic changes, related uncertainties and the potential for integrated adaptation response scenarios.

We would like to thank all the organisations that have been involved in contributing to this process. We hope they will continue to engage in the ongoing national discussion about how we adapt our society and economy in the short term and build a greener sustainable economy in the medium and longer term.

ACKNOWLEDGEMENTS

The Long-Term Adaptation Flagship Research Programme (LTAS) responds to the South African National Climate Change Response White Paper by undertaking climate change adaptation research and scenario planning for South Africa and the Southern African sub-region. The Department of Environmental Affairs (DEA) is leading the process in collaboration with technical research partner the South African National Biodiversity Institute (SANBI) and with technical and financial assistance from the Gesellschaft für Internationale Zusammenarbeit (GIZ).

The DEA would like to acknowledge the LTAS members of the Phase 1 and 2 Project Management Team who contributed to the development of the LTAS technical reports, namely Mr Shonisani Munzhedzi and Mr Vhalinavho Khavhagali (DEA), Prof Guy Midgley (SANBI), Ms Petra de Abreu and Ms Sarshen Scorgie (Conservation South Africa) and Dr Michaela Braun and Mr Zane Abdul (GIZ). The DEA would also like to thank the sector departments and other partners for their insights into this work, in particular the Department of Water Affairs (DWA), the Department of Agriculture, Forestry and Fisheries (DAFF), the National Disaster Management Centre (NDMC), the Department of Rural Development and Land Reform (DRDLR) and the South African Weather Services (SAWS).

Specifically, we would like to extend our gratitude to the groups, organisations and individuals who participated and provided technical expertise and key inputs to the "Long Term Adaptation Scenarios for South Africa report" report, namely Dr Guy Pegram, Ms Hannah Baleta and Daniel Seddon-Daines (Pegasys).

Furthermore, we thank the stakeholders who attended the LTAS workshops for their feedback and inputs on methodologies, content and results and in particular for assistance in developing the adaptation scenarios. Their contributions were instrumental to the development of this final report.

1. OVERVIEW AND HIGH LEVEL MESSAGES FROM THE ADAPTATION SCENARIOS

Overview

This study aims to explore the systemic implications of three distinct adaptation scenarios for South Africa. These scenarios are summarised briefly below and discussed in depth in **Section 4**.

It should be noted that, while in two of these scenarios a clear distinction has been made between a warmer and **wetter** and a warmer and **drier** future, the reality of climate change impacts on South Africa is likely to be more complex, in a number of ways. Firstly, as the climate warms different regions within South Africa could become wetter (on the east coast in particular) while other regions become drier (in the Northern Cape for instance). Secondly, South African rainfall will continue to fluctuate between drier and wetter conditions, sometimes lasting several years. While uncertainty over the impact of climate change on precipitation in particular persists, these scenarios nonetheless provide a useful heuristic device to explore in a robust and focused way possible future climates and their impact on South Africa.

Scenario one

Warmer and drier [temperature increase of <3°C in SA and reduced rainfall]: characterised by an increase in the frequency of drought events. In this scenario the limited availability of water intersects with growing demand in both agriculture (for irrigation) and urban areas (driven by population increase). The affordability of water drives a transformation in approaches to rural economic growth, water efficient urban design and the development of new models for managing food security.

Scenario two

Warmer and wetter [temperature increase of <3°C in SA and increased rainfall]: characterised by greater frequency of extreme rainfall events. In this scenario infrastructure and property is threatened and poor communities suffer as flooding increases in frequency and severity. These phenomena adversely affect human health, while the increasing variability of rainfall creates a shifting pattern of agricultural production. To adapt, flood resilience and socially sensitive settlements are prioritised as infrastructure design is rethought. Simultaneously, approaches to conservation of natural resources evolve further, as do innovative approaches to incentivising effective ecosystem management.

Scenario three

Hotter [a hotter scenario of >3°C in SA]: characterised by a significant shift in the frequency of extreme weather events, variability in precipitation and more significant impacts from wildfires and sea level rise. To cope with this radically new and variable climate the predictive power of early warning systems (EWSs) is prioritised as the weather becomes increasingly volatile. Urban spaces are reconfigured to preserve water and shield South Africans from the intense heat. Approaches to organising labour and to conservation are fundamentally rethought as traditional models are not effective in a significantly hotter climate. In the face of sea-level rise, managed retreat from less populated coastal areas is considered as a policy response.

Across the scenarios explored, this report concludes that increasing individual and community resilience to climate change cannot be separated from basic developmental interventions. The first and "no regrets" option for policy makers to adapt to climate change should be based on doing the basics better. Economically active, educated and healthy South Africans will have a greater capacity to avoid and recover from adverse climate events. Fulfilling the developmental objectives of providing basic life opportunities and improving the welfare of the general population should be a major building block of any response to climatic change. A critical component of human wellbeing is healthy ecosystems, and so no regrets options should

include maintaining and restoring ecosystems through approaches like ecosystem based adaptation.

High level messages

1. **There will be a significant change in the nature and scale of adaptation required if global mean temperature rises more than 2°C (roughly equivalent to a national temperature increase of 3°C)**

   This report suggests that in both a warmer drier and a warmer wetter scenario (<3°C increase in national mean average temperature in South Africa) there is likely to be a range of adverse impacts on the South African economy, society and the lives of its citizens. While these will be challenging, the scale of adaptation that will be required should national mean temperatures rise above 3°C, is fundamentally more extreme with an increased likelihood of undesirable outcomes.

   To avoid this future the mitigation of global carbon emissions must remain a priority for the international community and remain at the centre of South Africa's response to climate change, together with a focus on adaptation to impacts resulting from unavoidable further warming.

2. **Balanced development enables effective adaptation**

   Effective adaptation responses are founded on delivering balanced developmental objectives. A healthy, educated and financially secure population, living in a sustainable environment, will be better able to withstand and cope with extreme climate events. Capacitated communities, with access to basic services (water, health care and markets) and robust infrastructure will also be better able to recover from such events.

   Effective adaptation planning in South Africa, over a range of time scales, benefits from an understanding of how adaptation responses and development aspirations and needs can be mutually aligned.

   Such an approach requires a systemic understanding of how responses can enhance human security through building resilience in food, water, environmental and human health systems. These will rest increasingly on the resilience of built and ecological infrastructure, especially if global mitigation efforts fail to prevent exceedance of the 2°C global goal.

3. **Adaptation must focus on vulnerable communities, as they are most at risk from climate change**

   These communities include those directly dependent on rural livelihoods such as dry-land agriculture, and poor urban and mixed rural/urban communities. These communities are likely to experience significant adverse impacts with rural livelihoods at greater risk under warmer/drier scenarios and urban and mixed rural/urban communities under warmer/wetter scenarios.

   In both a wet and dry climate scenario the poor are likely to be the most vulnerable to extreme weather events (with the young and old at particular risk). In urban and peri-urban areas poorer communities are often located in areas that are unsuitable for human settlement due to local topological features which exacerbate flood risk.1

1 Department of Environmental Affairs (DEA), Climate Change Adaptation: Perspectives on Urban, Rural and Coastal Human Settlements in South Africa, Report no. 4 for the Long Term Adaptation Scenarios Flagship Research Programme, Department of Environmental Affairs, 2015

In rural areas subsistence communities are also expected to feel the acute implications of loss in agricultural productivity associated with a drying climate and reduced labour productivity as temperatures rise. This risk rises substantially in a hotter scenario.

4. **Adapting to an uncertain climate future with finite resources will result in trade-offs in the investment of resources**

   As the climate changes, it is probable that South Africa will face increasing stress on limited environmental resources. Simultaneously, South Africa will be challenged to adapt and shift its workforce to appropriate sectors of the economy. Investment in new infrastructure will also be needed. In all these cases, decisions about trade-offs between sectoral investments of natural, human and financial resources will be necessary.

5. **As the climate changes, systemic transformation will be needed in the medium and long term**

   To adapt to a changing climate, South Africa cannot rely on the assumption of effective autonomous and incremental adaptation responses alone. Responses will need to deliver systemic transformative change. Either the impacts of climate change may become severe enough to force transformative change, or South Africa may pre-empt the future impacts of climate change by transforming adequately to adapt to future impacts before they arise.

   To deliver these systemic changes a paradigm shift will be needed in the way society identifies and responds to long-term threats to its vision for growth, and a transformational approach to channelling human, social, political and financial capital to respond.

   Especially under a hotter scenario, the impacts on society will be wide reaching. As temperatures rise above 3°C in South Africa, life will become increasingly challenging for large numbers of its citizens. New approaches to work will need to be adopted to cope with declining labour productivity under increased heat stress. As sea level rise inundates coastal areas, planners could be forced to consider a managed retreat from marginal land. Because of increasing water scarcity, agricultural production would need to shift to higher-value export goods or might even become unviable with significant implications for national food security.

6. **Contingency planning for both wetter and drier climate futures is required in South Africa**

   Uncertainty about the climate future South Africa will encounter is still high, especially with regard to rainfall, where future trends are very uncertain at the local scale. In response South Africa could pursue a conscious risk management strategy based on contingency planning by building infrastructure to cope with both a wet and dry scenario.[2] This could require a degree of overdesign in infrastructure which implies increases in upfront costs that may not yield benefits for years or even decades.

   This approach would require a paradigm shift in approaches to optimisation and efficiency within government, and would necessitate a national dialogue.

2 Both hard physical, and ecological infrastructure should be considered as central.

7. Climate change has both positive and negative implications for national development pathways

The National Development Plan (NDP) does not fully take into account the risks and opportunities resulting from climate change impacts, especially where relevant for assessing individual, sectoral and cross-sectoral demands on natural resources. The availability of natural resources underpins many of the sectoral development strategies set out in the NDP.[3] Climate change could alter the availability of these natural resources with implications for cross-sectoral trade-offs in resource allocation. The LTAS climate and impact scenarios show that climate change has the potential to compromise some National Development Plan objectives. The hotter scenario in particular, creates substantive challenges to achieving balanced developmental objectives.

8. Climate change will likely accentuate inequality, undermining social justice and cohesion if South Africa does not adopt effective adaptation responses

Climate change has the potential to undermine already insecure communities, limiting their opportunities and accentuating inequality. Conversely the wealthy will continue to have the resources to avoid the full impacts of extreme weather events and afford the technologies to ameliorate the discomfort of a hot climate.

The inability of the state to insulate the poor majority from climate change and the visibly growing gap in quality of life experienced between the poor and the wealthy could cause growing social tensions.

9. The benefits of adapting outweigh the costs in the long run

The long term benefits of adaptation are likely to outweigh the initial costs especially when approaching the upper end of the warmer scenarios. Under increasingly hotter scenarios, the costs of adaptation investments rise and net benefits may ultimately start to decrease as adaptation limits are approached.[4]

The failure to adapt to climate change could present a significant societal and economic cost for South Africa, one that could be greater than the cost of adapting. For example, the initial investment required to upgrade roads is significant, but after 2040 the adaptation costs will be less, even in a hotter scenario, than the additional impact costs if current design standards were to be retained (see **Box 6**).[5]

10. Effective approaches to disaster risk reduction including early warning systems yield early returns on investment across all sectors

Regardless of the scenario encountered, the ability to coordinate an effective and rapid institutional response to extreme weather events, such as floods, droughts and storms will be vital. As part of effective disaster management, disaster risk reduction (DRR) before an event occurs is vital. To do this multiple national and municipal government departments,

3 National Planning Commission (NPC), National Development Plan 2030: Our Future – make it work, Pretoria: National Planning Commission, 2012.

4 DEA, The Economics of Adaptation to Future Climates in South Africa: An integrated biophysical and economic analysis, Report no. 6 for the Long Term Adaptation Scenarios Flagship Research Programme, Pretoria: Department of Environmental Affairs, 2015.

5 Ibid.

as well as communities and the private sector will need to be engaged and responsibilities well defined in advance to ensure effective EWSs and response systems are in place. This requires extensive capacity building at all levels and across sectors in order to improve understanding of effective approaches to disaster management and response systems.

Where effective processes and models have been established in particular regions of the country, efforts should be made to effectively transfer knowledge on disaster risk reduction and management (DRRM). This could be enabled by designating a specific entity or organisation as responsible for knowledge transfer such as disaster management centres and forums. Human and financial resources need to be made available for the implementation of DRR.

To ensure effective learning and promote on-going optimisation of DRR and response management, a robust performance monitoring framework and system should be established.

11. Institutions are unprepared to appropriately manage infrastructure under a more extreme and variable climate

South Africa has comparatively well-developed infrastructure (namely resilient water supply through inter-basin transfer systems). However, the institutional capacity to manage and direct the use of this infrastructure under a rapidly changing and uncertain climate has not been tested. For example, South Africa has not experienced a national-level extreme drought since 1992, and therefore nation-wide approaches to disaster management have not been exercised. Institutional capacity and knowledge need to be enhanced in order to respond to such risks.

12. South Africa's adaptation options are dependent on its development pathway which is linked to global mitigation efforts.

In an attempt to manage the impacts of climate change there is a risk that South Africa could select interventions that are emissions intensive. This would have implications for how South Africa participates in global emissions commitments.

For example, it is reasonable to assume that in a drying world efforts could be made in coastal urban areas to introduce large scale desalination technologies. While effective in increasing water supply, these technologies are highly energy and emissions intensive. Without renewable energy as a power source, this risks "lock-in" of the use of energy intensive technologies.

2. INTRODUCTION

The reality of South Africa's vulnerability to climate variability and climate change is increasingly apparent.

South Africa is sensitive to human-caused climate change. Air temperatures have increased at least 50% more than the global annual average of 0.65°C over the last five decades, raising the very real possibility that in a world of >2 degrees of temperature change, South Africa could experiences changes of over 3 degrees.[6]

South Africa has not experienced a significant multi-year country-wide drought in its post-apartheid history. Development gains since 1994 have been made in the context of above average rainfall conditions, with a relatively low degree of inter-annual variability. Evidence of increasing climate variability can be observed through the major southern Cape drought[7] in 2010 which was followed by flooding in 2012.[8] Localised and in some cases regional climate extremes have exacted significant economic damages in the last few years, especially relating to flooding events and wildfires, and to a lesser extent due to drought. The recent damages and loss of life associated with the high rainfall events of March 2014 highlight the current vulnerability and inadequacy of EWSs, given that below-average rainfall conditions were predicted by national long-range forecasts. During the floods, major pieces of infrastructure including transport routes and bridges were damaged. These impacts are projected to increase as future climate change accelerates.

Sustained warming and increasing rainfall variability over the short term (next decade) will have increasingly adverse effects on key sectors of South Africa's economy in the absence of effective adaptation responses. Early impacts will largely be felt by the poor. Subsistence farmers and those dependent on rain fed agriculture will be significantly impacted by increasing temperatures and drying trends. Similarly, the increasing frequency of extreme weather events is likely to have a disproportionate impact on the poorest in society (rural and urban), amplifying existing social inequalities. Because of a history of rainfall variability, South Africa's national water supply system and planning is among the most sophisticated in the world, and provides substantive resilience to future climate change. However, weaknesses in water supply systems and water quality trends at local and regional levels reduce this resilience.[9]

In the short term, the increase in climate variability, potential increased risk of drought and warming trends, threaten South Africa's vision to eliminate poverty and reduce inequality through development. Over the medium and long term, sustained trends in warming, rainfall variability and climate change could result in constraints for South Africa's development aspirations, as articulated most recently by the National Development Plan (NDP).

A bold and transformative vision for inclusive development has been laid out under the NDP. The objectives it lays out have the potential to transform the country, eliminating poverty and reducing inequality by 2030. Delivering this vision requires significant investment, but it is predicated on a number of informed assumptions about the nature

6 DEA. Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate Trends and Scenarios for South Africa. Pretoria: Department of Environmental Affairs, 2013.

7 S Cape drought intensifying, *News 24*, 25 May 2010. http://www.news24.com/SouthAfrica/News/S-Cape-drought-intensifying-20100525

8 Heavy flooding and snow keeps SA on its toes, *Mail & Guardian*, 16 July 2012, http://mg.co.za/article/2012-07-16-heavy-flooding-and-snow-keeps-sa-on-its-toes

9 DEA, Economics of Adaptation.

of the environment, the services it provides and living conditions it creates for citizens.

The NDP does not fully take into account the risks and opportunities due to climate change impacts. The availability of natural resources underpins many of the sectoral development strategies set out in the NDP.[10] Climate change could alter the availability of these natural resources with implications for cross-sectoral trade-offs in resource allocation. The LTAS scenarios show that climate change has the potential to compromise some NDP objectives, and hotter scenarios especially create substantive challenges to achieving balanced developmental objectives.

For example, in a drier scenario the objectives of ensuring universal access to clean water, creating ~1 million new jobs in the agricultural sector, partly via increased investment in irrigation in key river basins, and upgrading informal settlements by 2030 are all challenged.

An effective response to the risks created by climate variability and climate change would be usefully based on an understanding of the range of adaptation measures available as well as the institutional vulnerability and capacity to address these risks.

The challenge now for South Africa is how to anticipate the ways in which climate variability and climate change could impact South Africa's development ambitions and put in place a strategy for adaptation and resilience – even as uncertainty over the way climate change will impact South Africa persists.

At international level 2015 will be an inflection point in the global response to climate change.

In 2015 the international community will reach a defining milestone in its response to tackling global climate change. The Paris Meeting of the Parties (COP21) will need to agree on a successor to the Kyoto Protocol in order to deliver an effective international framework for addressing climate change by 2020. The conclusion of an international deal would provide greater clarity on plausible global emissions trajectories, providing an opportunity for South Africa to refine its adaptation scenarios and narrow the range of risks and the adaptation measures open to it.

By building adaptation scenarios now, the insights and framework they provide can be adjusted in the light of new information to support effective decision making and deliver the systemic adaptation responses that will be needed to support South Africa's national development.

10 NPC, National Development Plan.

3. APPROACH

3.1 Introduction

In order to create adaptation scenarios the traditional scenarios planning process has been drawn upon, but also adapted.

This document has brought together robust thinking on both climate futures and development trajectories for South Africa, which have been applied using scenario planning techniques. However it was found necessary to step beyond typical scenario approaches in order to construct adaptation scenarios. This is because adaptation requires thinking about the different potential climates South Africa might face in the future, and the economic, social and environmental landscape that might be impacted (which will be determined by the development trajectory South Africa pursues).

Below, **Section 3.2** provides a brief overview of conventional scenario planning approaches; how they can help to understand climate change and the way in which they need to be augmented to inform adaptation scenarios. **Section 3.3** provides further details specifically on how South Africa's adaptation scenarios were developed.

3.2 Scenario planning

Scenario planning provides a means to explore and prepare for alternative futures in situations where significant uncertainty exists. Scenario planning helps to avoid the dangers of simplistic, one-dimensional and linear thinking. By identifying 'what if' scenarios, stakeholders can identify potential response options and isolate low and no regrets options.

There is significant uncertainty over how climate change will manifest itself in South Africa, which makes scenario planning a useful tool. We can be confident that climate change is already, and will increasingly, impact life in South Africa. Increases in temperature are more certain than rainfall projections. Significant uncertainty exists about how many impacts will manifest, with climate modelling suggesting the potential for both a wetter and a drier future. Developing distinct climate futures helps us explore and tease out the socio-economic impacts of climate change. These futures also provide a basis on which rich climate adaptation scenarios can be constructed.

Climate futures provide a basis on which to develop adaption scenarios. An adaptation scenario is a description of a suite of adaptation responses that may be implemented across a range of sectors, in response to the impacts of climate change.

Adaptation scenarios are necessarily complex. This is because identifying the way society will respond to a future climate requires us to think not only about different climate scenarios but also about the way society will have developed in the future. In a sense adaptation scenarios are informed by the meeting of two related scenarios – a set of climate futures and a set of development trajectories. The section below describes the approach taken to building adaptation scenarios in this report in more detail.

3.3 Building adaptation scenarios

To construct adaptation scenarios, a number of key inputs from both LTAS Phase 1 (including a detailed policy alignment review) and LTAS Phase 2 were drawn on. LTAS Phase 1 has delivered a set of four robust climate futures based on fundamental climate modelling. This was complemented by a stakeholder engagement process that considered South Africa's future development trajectories and defined two fundamental scenarios – a collaborative decarbonising world and a carbonising one. This provided a sound basis on which to construct adaptation scenarios through consultation with stakeholder experts and through desk based analysis. This process was supported in its later stages by early results from detailed econometric modelling that was undertaken to explore the impacts of climate shifts on water, infrastructure and agriculture.

Further information on the approach is provided below and summarised in **Figure 1**.

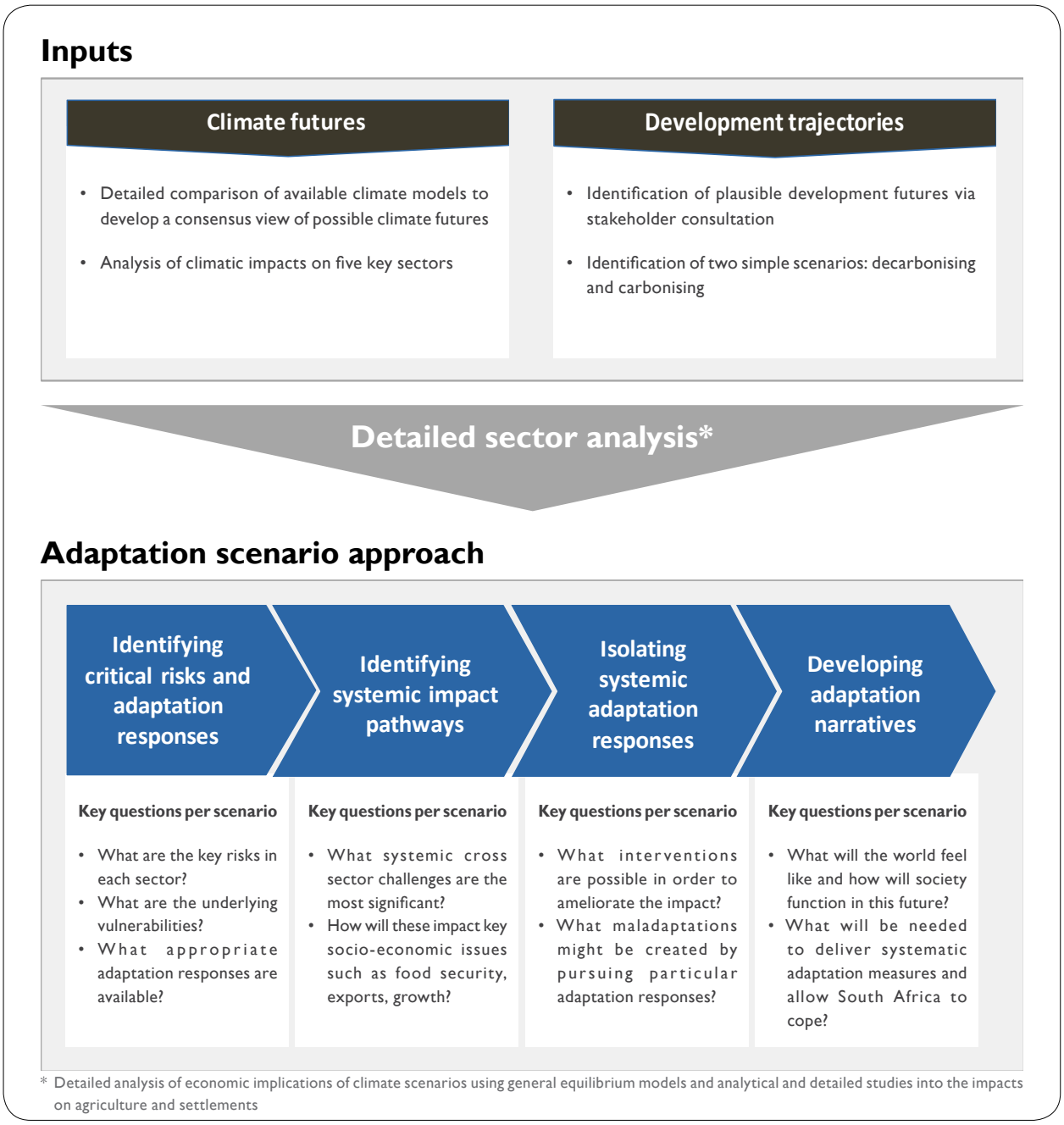


Figure 1: Overview of the approach to developing climate adaptation scenarios.

Identifying climate futures

Prior efforts under LTAS Phase 1 provided a robust set of four fundamental climate scenarios for South Africa up to 2050, with different degrees of change and likelihood which reflect the impacts of global mitigation over time. These scenarios are:

- Warmer (<3°C above 1961–2000) and wetter, with greater frequency of extreme rainfall events.
- Warmer (<3°C above 1961–2000) and drier, with an increase in the frequency of drought events and somewhat greater frequency of extreme rainfall events
- Hotter (>3°C above 1961–2000) and wetter, with substantially greater frequency of extreme rainfall events.
- Hotter (>3°C above 1961–2000) and drier, with a substantial increase in the frequency of drought events and greater frequency of extreme rainfall events.

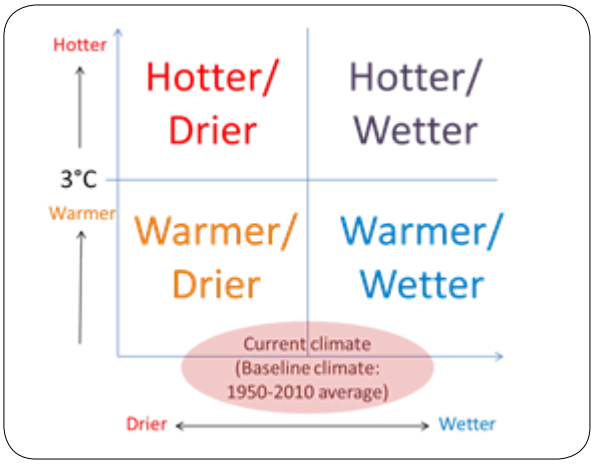


Figure 2: LTAS Phase 1 plausible climate futures.

LTAS Phase 1 also provided detailed insights derived from fundamental climate modelling and describing the possible physical impacts of climate change in South Africa for the water, agriculture and forestry, human health, marine fisheries and biodiversity sectors. The six distinct hydrological zones identified within South Africa are impacted differently as indicated in the table below.

Table 1 Rainfall projections for each of South Africa's six hydrological zones [11]

Scenario	Limpopo/ Olifants/Inkomati	Pongola-Umzimkulu	Vaal	Orange	Mzimvubu-Tsitsikamma	Breede-Gouritz/ Berg
1: warmer/ wetter	↑ spring and summer	↑ spring	↑ spring and summer	↑ in all seasons	↑ in all seasons	↓ autumn, ↑ winter and spring
2: warmer/ drier	↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ in all seasons, strongly ↓ summer and autumn	↓ in all seasons, strongly ↓ in the west
3: hotter/ wetter	Strongly ↑ spring and summer	Strongly ↑ spring	↑ spring and summer	↑ in all seasons	Strongly ↑ in all seasons	↓ autumn, ↑ winter and spring
4: hotter/ drier	Strongly ↓ summer, spring and autumn	↓ spring and strongly ↓ summer and autumn	↓ summer and spring and strongly ↓ autumn	↓ summer, autumn and spring	↓ all seasons, strongly ↓ in summer and autumn	↓ all seasons, strongly ↓ in the west

11 DEA, GIZ & SANBI, Climate trends and scenarios, Climate and impacts factsheet 2 of 7, 2013. http://www.sanbi.org/sites/default/files/documents/documents/ltas-factsheetclimate-trends-and-scenarios2013.pdf

Moving from climate to development trajectories

Adaptation responses are not entirely distinct from the broader category of developmental interventions that would also reduce the underlying vulnerability of people, communities and the economy. As a result, in order to consider any set of future adaptation responses, we must also think about possible development trajectories South Africa will pursue. To support this, a detailed policy alignment review of relevant legislation and a stakeholder consultation exercise were conducted to identify the key development trajectories for South Africa.

To ensure development trajectories were plausible the NDP, as well as projections for regional growth and opportunity indicated in the Strategic Integrated Projects (SIPS) were carefully considered. Developmental uncertainties around appropriate mechanisms for social inclusion, delivering equity and environmental sustainability were closely interrogated. These issues were juxtaposed with considerations regarding the economic growth of South Africa, which in some cases does not automatically result in social development and equity (or adequate environmental management).

Through the NDP and SIPS, as well as the stakeholder process, four broad development trajectories were identified, indicating different development approaches for South Africa:

- An urbanising service led economy
- A high growth economy based on primary and extractive industries
- A redistributive and increasingly decentralised economy
- A low carbon and 'green' economy

Through this process a strong argument was made that in order to be useful in informing adaptation scenarios the development trajectories should both a) be simplified and b) consider the international community's mitigation response to climate change – as this would have a direct impact on South Africa's development trajectory and its adaptation options.

This provided us with two high-level global development trajectories, directly linked to a set of emissions scenarios:

- An unmitigated scenario with limited global efforts to decarbonise the economy
- A mitigated scenario with significant global action to limit emissions and decarbonise.

3.4 Detailed approach

Establishing a clear set of climate scenarios and defining (in broad terms) the development future South Africa might face, provided us with a series of lenses through which to explore plausible adaptation responses.

Identifying risks, vulnerabilities and adaptation options through stakeholder consultation

To enrich the technical analysis of climatic impacts, workshops where held with a diverse range of South African stakeholders including local, provincial and national government and the NGO sector. The participants were invited by the Department of Environmental Affairs. The two workshops, held in Johannesburg between January and March, helped to identify underlying vulnerabilities, key risks and future response options under each scenario. Representatives from government, the private sector and civil society were present.

These sessions provided insights into the interlinkages between sectors and helped to identify the repercussions of negative impacts in one area – both for other sectors and for communities and society. This laid a solid foundation for the next phase of analysis.[12]

Identifying key impact pathways under each scenario

Based on inputs from previous phases a series of system diagrams where developed – one for each scenario. These provided a tool and basis on which to explore the inter-sectoral impacts of different climate change scenarios.

From this analysis a number of key impact pathways were identified. By impact pathways we refer to the secondary impacts that, for instance a lack of water could have on the rural agricultural sector, the jobs available and the repercussions for rural to urban migration and national food security as a result. This provided a basis on which to identify the climatic impacts which would be most pronounced under one scenario, as distinct from another. Three distinct climate futures were selected: drier, wetter and hotter.

Warmer/Drier Temperature increase <3°C and drier	Warmer/Wetter Temperature increase <3°C and wetter	Hotter Scenario three: A hotter scenario, >3°C
		

12 Although a wide range of representatives were present, future phases of this work should consider the inclusion of increased engagement with sector representative bodies and economic clusters such as agriculture and insurance.

This approach recognises that significant variability and uncertainty exists within scenarios. It does not aim to be an exhaustive analysis of the potential inter-linkages and relationships between climate, sectors and socio-economic end results but it does provide a way to explore what, on balance, will be the priority issues under different scenarios.

Isolating systemic adaptation responses

This supported an analysis to define how systemic adaptation measures could contribute to ameliorating the impacts of major climate change impacts in each scenario – identifying a number of plausible systemic interventions.

Construction of key narratives and identification of systemic adaptation responses

Each scenario has three components. Firstly, to help communicate the implications of each plausible adaptation scenario a series of personal "day in the life of" narratives have been developed. These describe the reality that might be faced by an individual in South Africa and provide a stylised means to illustrate the potential impacts on a range of sectors.

Major impacts expected are discussed under each climate scenario, attempting to highlight the systemic and intersectoral impacts and trade-offs this could have on key issues such as food security, quality of life and exports. As has been noted above these scenarios are not designed to be an exhaustive description of all the possible impacts of climate change on the socio-economic landscape of South Africa. Instead we aim to provide a snapshot of the sectors that will be most directly impacted (on the basis of available data and insights) and the thematic issues that arise as a result.

Each scenario also provides a description of the systemic adaptation responses that will be needed in order to respond to this climate future. While autonomous and incremental adaptation measures will, and must, be delivered to reduce the impact of climate change there will also be a need for bolder, more transformative changes. By drawing on stakeholder and expert input we have attempted to identify these bold and cross-cutting interventions – to serve as a basis to inform discussion and prompt action.

4. ADAPTATION SCENARIOS

4.1 Systems perspective

In order to build the adaptation scenarios, a meta-system diagram was developed to indicate the different levels of association between sectors and interactions between them. Specific elements relevant to each adaptation scenario are highlighted in subsequent diagrams to indicate major links.

The driving climatic forces of temperature, precipitation, evapotranspiration and carbon levels are indicated by the inner circles of the diagram. These in turn affect core elements of the 'system' which include (among others) water availability, sea level rise and fire. Natural resources, agriculture, industry, labour productivity and settlements are a selection of the major sectors impacted. Outcomes such as human health, biodiversity and ecosystem services, food security, economic development and social equity, indicated on the outer limits of the systems diagram, are as a result of the interactions of these sectors with each other and with relation to climate.

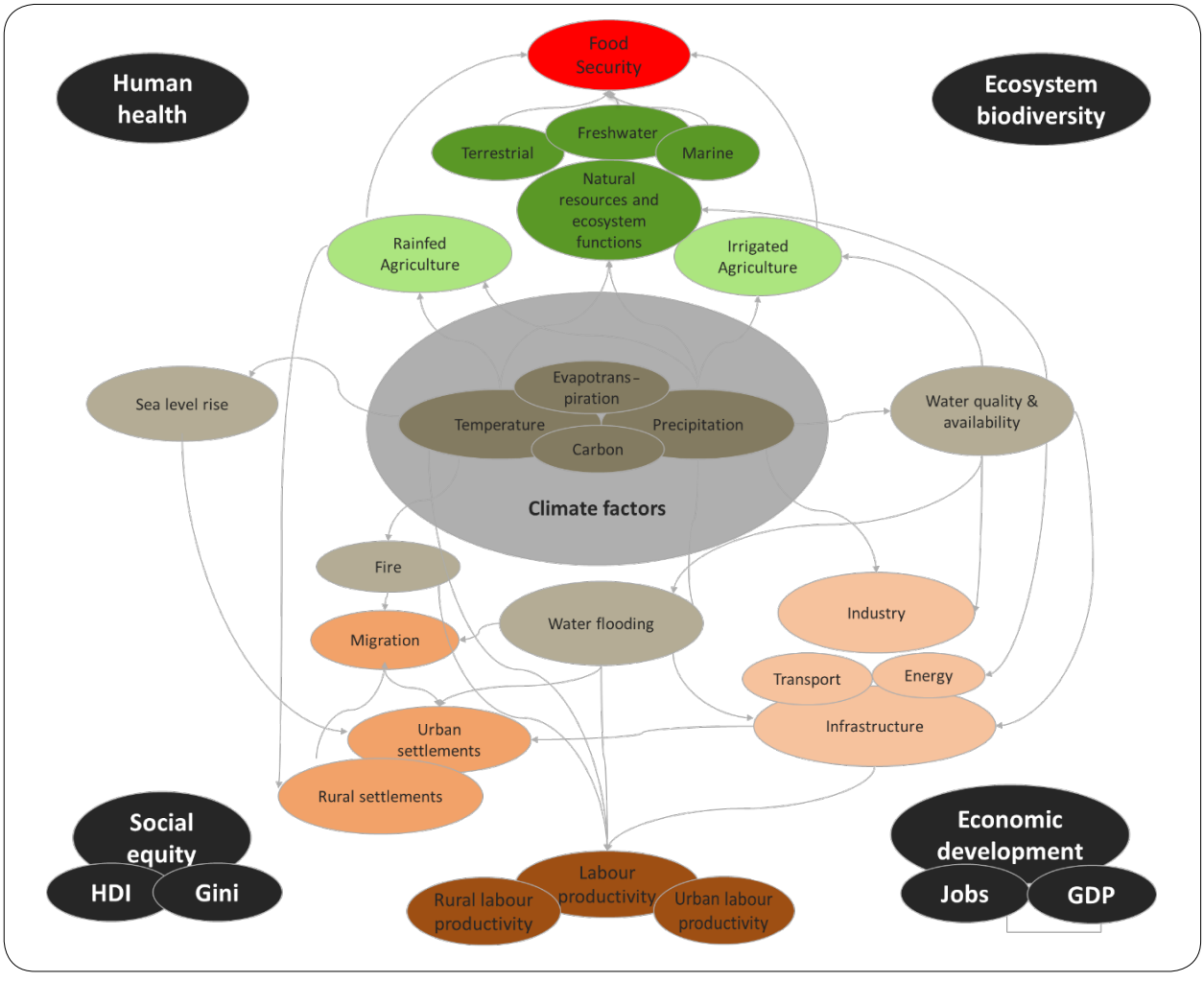


Figure 3: Systems diagram

4.2 Adaptation Scenario 1: A warmer but drier climate in South Africa

Summary narrative

Mr Mabonya wakes up at his home, 5 km from Lichtenburg in the North West province. Its 3.30 am and he's woken up early to start work and avoid the midday heat. He looks out over the maize field on which he depends for his living. He knows that soon he will no longer be able to afford the water which he has had to use in increasing quantities over the last three years to irrigate his crop. The rainfall on which he used to rely has long since failed to be a reliable source.

Fortunately his crop, unlike that of his neighbours, has avoided the fires that swept through the area twice in the last three years. But Mr Mabonya knows that, with his savings depleted, he won't be able to survive should he lose a single harvest to fire, or should yields drop any lower due to the droughts that come with increasing frequency.

Eventually, and with much regret, Mr Mabonya decides to sell his land to a large commercial farming operation that's been buying up land in the area. They can afford the water to irrigate crops and produce the expensive exports that are sent to foreign markets.

Anyway, maybe it's not so bad, Mr Mabonya thinks to himself. Life out in Lichtenburg has become increasingly uncomfortable. The heat in the summer is stifling and the rivers and dams that used to be a welcome source of refreshment have either dried up, or are jealously guarded by others in the community. After selling his land, Mr Mabonya, like many of his neighbours moves to Johannesburg where he stays with his cousin.

Life in the city is hard and waves of rural migrants have arrived on the outskirts of Jozi over the last few years, driven by drought and the decline of rural towns and smallholder farming. Eventually Mr Mabonya finds a small empty plot in an outlying township to call home.

Although he finds a job serving as a security guard he struggles to keep pace with the cost of living. Food prices are becoming inflated as agricultural production switches towards exports and water prices rise. Heat waves become more frequent and Mr Mabonya works different hours in order to avoid the heat.

In the summer months the rain is intense and flash floods are frequent. Mr Mabonya finds that the empty plot of land he built on becomes a watercourse when it rains and his home is frequently flooded.

Scenario specific systems diagram

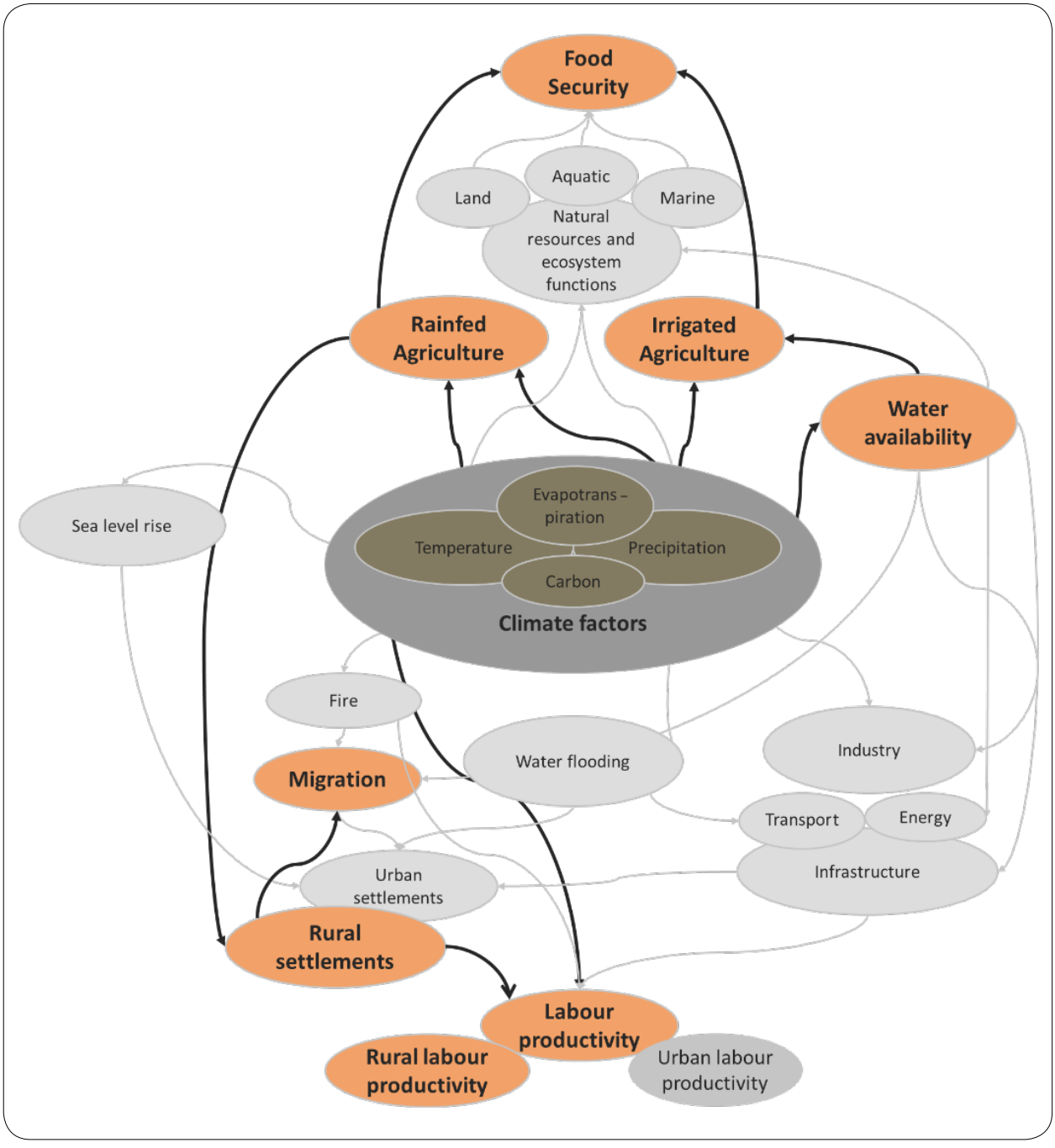


Figure 4: Systems diagram: A warmer but drier climate in South Africa

Vulnerability assessment

In a drier scenario the limited availability of water, and the implications for price, become key determinants of economic and demographic activity driving transition across South Africa. In a drier world water availability declines across most of South Africa with the central, north and south-west of the country most severely impacted. Interbasin transfers allow water resources to be shifted between regions and sectors, supporting adaptive change.[13] However, with increasing demands across multiple regions this safety net breaks down as we approach a hotter scenario.

Demand for water in agriculture increases dramatically. Irrigation needs increase by 15–30% in dry areas, where surface water already needs to be supplemented with irrigation. In these areas agricultural production will be seriously undermined (with the implications felt most in the dry Western Cape and the north of the country).

This sustained drying undermines agriculture and agroprocessing sectors. Without affordable water for irrigation and with reduced rainfall, yields are impacted negatively with implications for domestic production. In drought years a 40% reduction in yield for key crops is expected with a 7% drop in sugarcane yield forecast for every 10% reduction in rainfall.

By 2020, 28% of the land suitable for apple production is gone and by 2050 production is expected to be confined to high-lying areas such as the Koue Bokkeveld and Ceres.

As much as 30% of the total production area suitable for vines is expected to be impacted. While new opportunities may open up in the Overberg, the human capital built up in the Western Cape and its infrastructure (including cellars, vine stocks, barrelling and so on) are undermined. South Africa's "New World" wine status suffers and tourism and wine exports drop[14], reducing foreign exchange earnings.

In a scenario in which South Africa makes a concerted effort to retain its agricultural production, **competition for scarce water resources with mining, urban, peri-urban and rural settlements intensifies driving up price and potentially lowering the quality.** Expanding urban areas, driven by rural to urban migration, create increased demand for smaller water reserves. The political imperative of meeting urban water needs and simultaneously supplying agriculture drives up prices.

With water increasingly expensive, agricultural production has no choice but to shift to high-value export goods. The inflated price of water means that only production of high-value export crops or drought resilient varieties will be feasible. The production of both maize and wheat is likely to be dramatically reduced as smaller farmers either retreat from the land or switch/ are subsumed into larger commercial farms producing higher-value export commodities. Above 28°C heat stress begins in most breeds. This will have an impact on the viability of livestock production both at commercial and subsistence level.[15]

A focus on exports creates food security issues for the majority. South Africa's production of grain falls dramatically with significant impacts for smallholdings of wheat and maize. This undermines national food security and increasing quantities of basic foodstuffs are imported

13 South Africa has 28 inter-basin transfer schemes with a total transfer capacity of over 7 billion m^3/year (Department of Water Affairs 2013).

14 1.3% of total exports in 2009.

15 DEA, LTAS Phase 1 Technical Summary, Pretoria: DEA, SANBI & GIZ, 2013.

creating reliance on increasingly volatile global commodity markets.

The following case gives an indication of current experiences drought or stress on livestock and industry as a result of insufficient rainfall (subsistence and commercial). A future drying climate will further exacerbate these impacts.

Box 1: Example of drought and flood impacts for agriculture and settlements in the North West

The 2013 drought in the North West Province of South Africa cost R43 million from National Treasury in drought relief. This included 14 000 bags of fodder to 20 000 farmers.[16] The drought resulted in a large number of livestock dying.[17] Small-scale farmers were particularly affected. The drought broke in February 2014. Although good news for the farmers, the high intensity of the rainfall caused localised flooding affecting a large number of RDP homes.[18]

Rural towns experience depopulation as agricultural jobs are lost in the shift to more mechanised and efficient export crop production. South Africa is already experiencing a hollowing out of rural areas, particularly in the eastern part of the Western Cape, western part of the Eastern Cape, the Northern Cape and much of the Free State. The shift in agricultural production from subsistence crops to exports is linked with higher rates of efficiency and potentially fewer jobs accelerating the trend in rural to urban migration.

As rural to urban migration accelerates, existing social tensions are exacerbated. Increased rural–urban migration places additional pressure on cities to deliver basic services and provide affordable water to their new citizens. The proportion of total national water consumed in urban settlements has risen significantly, accounting for 23% of total water consumption in 2009.[19] Cities will be increasingly water stressed, with the exception of cities on the east coast, which are expected to experience increased rainfall. As a result, the introduction of water efficiency, water harvesting and desalination technologies are expected in the majority of urban and industrial areas, creating often heavy energy demands, which in turn, depending on the form of energy production, place an additional demand on water resources.

While incremental adaptation measures will be taken in response to this drier future, bold new systemic responses are introduced to manage the changing climate, and its impact on South Africa. Through this project, stakeholder consultation has identified a number of significant adaptation responses as being necessary, if South Africa is to effectively manage this undesirable future.

16 Relief for drought stricken NW farmers, *Farmer's Weekly*, November 28, 2013. http://www.farmersweekly.co.za/news.aspx?id=48179&h=Relief-for-drought-stricken-NW-farmers

17 North West drought from above, *Farmer's Weekly*, November 26, 2013. http://farmersweekly.co.za/news.aspx?id=48008&h=North%20West%20drought%20from%20above

18 Heavy rains break North West Drought, *Farmer's Weekly*, February 10 2014. http://www.farmersweekly.co.za/news.aspx?id=53388&h=Heavy-rains-break-North-West-drought

19 Department of Water Affairs and Forestry (DWAF), The Water for Growth and Development Framework, Pretoria: Department of Water Affairs and Forestry, 2009. https://www.dwaf.gov.za/WFGD/documents/WFGD_Frameworkv7.pdf

Box 2: Biomes are threatened by climate change

Grassland ecosystems are the most vulnerable to future climate change under all climate scenarios. Large portions of the biome are likely to be replaced with savannah through a woody species invasion.

The expansion of deserts is projected to take place in the western parts of South Africa as temperatures progressively increase and rainfall decreases.

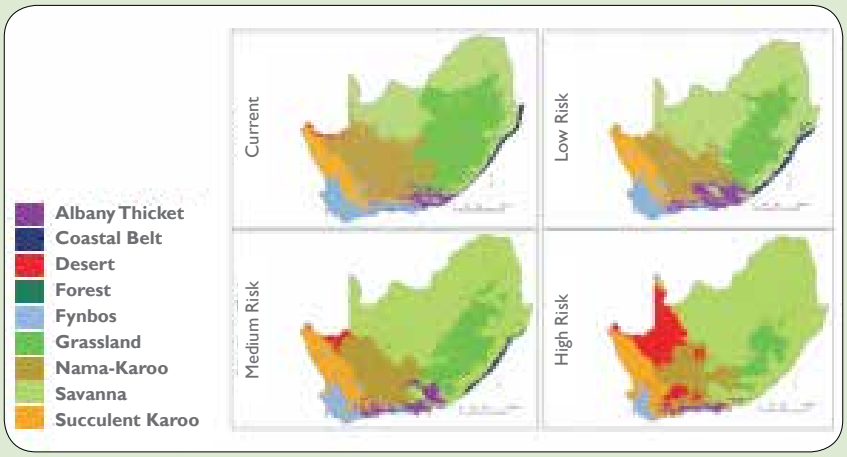


Figure 5: Projections of biome shifts under low, medium and high risk climate scenarios until 2050 (DEA 2013).

Fynbos, a form of vegetation rich in biodiversity, is only found in the Western Cape. The 5 500 plant species endemic to this ecosystem are threatened by the projected 10–30% reduction in winter rainfall by 2050. Although resilient to dry conditions, further drying will increase the risk of fires and make it even harder for native plants to survive.[20] As the region is their only native habitat there are few alternatives and climate change threatens their existence.

Systemic adaptation responses for a warmer/drier scenario

Effective early warning systems for drought

Developing credible and accessible EWSs can play an important role in helping farmers and communities manage drought. EWSs can also support government by acting as triggers to mobilise emergency resources.

To build credibility standardised drought indices are needed that incorporate precipitation, hydrology and land use factors to reliably predict drought events. Information will need to be accessible and the introduction of effective technologies, like mobile telephony, can accelerate the timely dissemination of information to farmers. Mobile telephony could also provide a means to obtain data on local weather conditions that could be fed into analyses to improve predictive models for droughts at the local level. Farmers should also receive adequate extension support on how best to adapt to climate impacts including through use of climate-smart agriculture (CSA). CSA includes conservation agriculture, a focus on food security and on adaptation and mitigation to climate change. Landcare should be integrated with the

20 South African Press Association (SAPA), Fynbos Threatened by Climate change, *News 24* (online newspaper), 17 May 2012. http://www.news24.com/SciTech/News/Fynbos-threatened-by-climate-change-20120517-3

Natural Resource Programmes within the Department of Environmental Affairs (DEA) to avoid a disjuncture between the mandates of different sectors.

Collation of comprehensive and rich data on drought incidence would help inform a more systematic approach to targeting resources to address underlying vulnerabilities, support community level capacity building and provide an evidence base on which appropriate and affordable insurance products could be offered.

Reconceiving rural economic growth

Under a drier climatic scenario, the opportunities for rural smallholder agriculture will be put under sustained pressure and will arguably be undermined in many areas.

Although it's conceivable that large swathes of rural land could be irrigated under centrally directed initiatives, it's likely that this would come at a huge cost due to rising water prices. In this situation the investment needed for irrigation is likely to be beyond the reach of the public purse, individual smallholders and some commercial farmers.

To deliver the NDP's objectives for an inclusive rural economy, a paradigm shift will arguably be needed in the way rural agricultural areas, and their economic role, is planned and delivered.

This could include a focus on developing a policy environment to support the development of agro-enterprise clusters that create new value-adding services in rural areas and increase revenue streams for smallholders. In parallel new efforts would be required to address market access constraints, ensure value-chains can be integrated and ensure that producer organisations can develop and provide support services to farmers.

A radical rethinking of urban design based on water preservation and efficiency

Under our drier scenario, rural to urban migration is likely to accelerate significantly as a result both of internal dynamics and possibly in-migration from South Africa's regional neighbours. As the cost of water increases dramatically a substantive reassessment of urban design will be required to handle both the rate of new arrivals and the need to deliver basic services with greater efficiency.

Policy will be implemented to create an imperative for municipal and private sector planners to design "intelligent/resilient" and water resource efficient urban spaces. At the same time aggressive penalties will be introduced for inefficient water use via tariff structures and taxes.

New technological innovations will be found to deliver effective services to urban citizens. These might include a dramatic uptake in effluent reuse and large-scale and micro-desalinisation technologies based on renewable energy or moisture capture technologies.

Shifting behavioural change and patterns of resource production and consumption

These patterns will be consistent with the new realities of a water scarce and more urbanised population. The misuse of water will become socially taboo and individuals and organisations that fail to prioritise it will face negative community and consumer responses.

As a result manufacturing will refocus on delivering water efficient processes and products. At the same time new procurement standards for water efficiency and foot printing will be introduced, first by government and by private companies creating quick adoption by suppliers who need to fulfil strict requirements. Private sector players will face increasing pressure to incorporate direct water efficiency into their building, factory and overall location design considerations.

Building food and energy buffers

In a drier scenario policy makers will need to assertively intervene to ensure markets provide basic social goods (energy and food). This could include, but would not necessarily be limited to actions to support:

- **Food security:** In response to threats to food security policy makers will encourage the establishment of larger stockpiles and strategic reserves. This could counterbalance the impact of severe droughts on basic consumables and insulate low-income consumers from the potential short term volatility of purchasing replacement imports on international markets. This might be accompanied by new policy interventions to secure a minimum level of cultivable land for basic food production and efforts to discourage exports of key products. In parallel, drought resistant and selective genetically modified organism (GMO) crops could be introduced where feasible to improve food security. Closer integration of food supply networks with partners in the region, and establishment of shared reserves could also be considered.
- **Regional energy integration:** the negotiation of agreements to support importation of hydropower from Zambia and Mozambique is accelerated. In parallel compacts with regional partners are solidified to compensate for loss of capacity from South African hydropower stations and to meet increased energy demand for large desalination plants.

Restore, protect and maintain biodiversity and ecological infrastructure

In a drier climate, competition for resources will put stress on functioning ecosystems. This will be particularly challenging in rural areas where people have no alternative but to depend for their livelihoods on direct access to, and use of, natural resources from the land. Novel approaches to supporting biodiversity and ecological services will be necessary in addition to expanding existing programmes such as the Expanded Public Works Programme (EPWP), natural resources management (NRM) and catchment management agencies (CMAs).

In response to increasing water constraints effective delivery and innovation in approaches to catchment management are necessary. Implementation of catchment management strategies is required to ensure that the 8% of South Africa's land area (water towers) that supplies 50% of the country's water supply is maintained. The governance of and funding allocation to catchment management agencies (CMAs) is critical to their effectiveness in implementing catchment management strategies (CMS). Water pricing policy revisions need to be implemented so that water use charges are allocated back to catchment rehabilitation and perverse incentives for water use are removed.

In addition to building on existing NRM approaches, new strategies for delivery of ecosystem services need to be enabled. These approaches include payment for ecosystem services (PES) whereby downstream water users compensate those upstream for responsible management of the catchment. Additional options include a municipal 'green fee' charged to water users within a local municipality. The money is ring fenced and is allocated back to the catchment to incentivise landowners to manage land sustainably. Business models for incentivising the elimination of alien invasive species are another potential adaptive response incentivising the private sector. Examples include work already being carried out by Santam, the World Wildlife Foundation (WWF) and SAB-Miller among others. But these efforts will need to be scaled up. Other examples include expansion of NRM land user incentive programmes to incentivise more landowners to manage land sustainably for the long term, and also involving the private sector such as retailers in supporting small-scale farmers in gaining access to markets for products such as veld-raised red meat and crops that come from farms that are sustainably managed.

4.3 Adaptation Scenario 2: A warmer but wetter climate in South Africa

Summary narrative

The water supply to the 3.4 million people in and around Durban is at risk. Mr Naidoo is returning from Inanda Dam where the bulk water storage infrastructure and dam spillway have been seriously damaged by the heavy rainfall experienced this spring. The dam may break, flooding farmland, homes and sensitive aquatic systems. Precious stored water for drier months will be lost too.

Mr Naidoo gazes out over the lush, green landscape which has recently been battered by intense rainfall. He sympathises with the cane farmers. Even though the rain increases their yield, for the second year running their harvests have been destroyed by pests like *Eldana* and *Chilo*. If this continues, the farmers will be forced to change crops or start to grow cane elsewhere.

On route back to Durban, he passes through KwaMashu. They too have been devastated by the rains. Many of the mud homes and small RDP houses built on the slopes of hills have been damaged or washed away. Sadly, there was no warning system for most of the residents of the settlement, and so many of their precious belongings were destroyed, leaving them destitute. Without homes and with poor drainage, water and sanitation are a problem. Cases of malaria, cholera and dysentery are putting great pressure on the health system. People are unable to get health care due to the large numbers needing help in the face of inadequate health infrastructure and an inadequate number of health care workers. Mr Naidoo thinks about his friends living there, who are constantly sick and unable to work, which is causing financial worries.

Without proper drainage systems, the water comes gushing down the slopes, tearing up the road surfaces and causing soil erosion. Many buildings have collapsed as a result. Mr Naidoo's car hits a large pothole as he enters the city. This is a new one, which he knows will be there for a while, since the municipality is unable to keep up with the repairs. The roads are not built to withstand the current climate conditions and so repairs are seemingly endless.

Next is a consultation with the port authority on how to withstand both the storm surges and increased flooding from the rivers flowing into the bay. Due to the high seas and damage to infrastructure, the harbour has not been able to load or offload the shipping containers recently. Not only the national trade balance, but food security is at risk as Durban harbour is a core port for the entire country. High value crop exports from the interior of

the country are rotting at the ship berths, while staple food supplies and other materials are stuck on the ships.

Finally Mr Naidoo heads home to a dark home. There is no electricity again because flooding has destroyed the transport routes for coal to the upcountry power stations. To make matters worse, the coal is wet making it less efficient and the power station has experienced flood damage too. This is not the first time this has happened nor will it be the last.

Scenario specific diagram

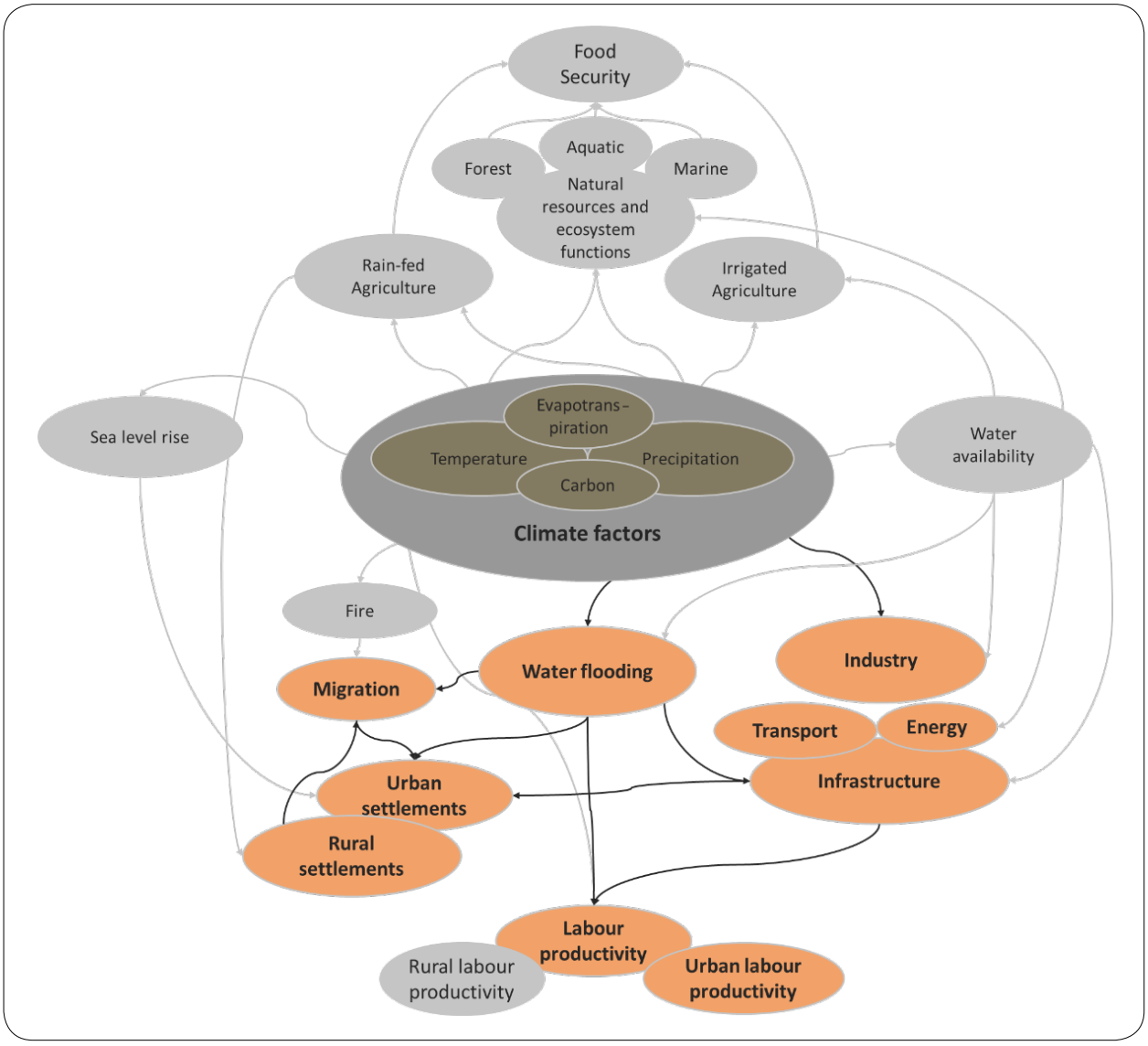


Figure 6: Systems diagram: A warmer but wetter climate in South Africa

Vulnerability assessment

In a wetter world, the impacts associated with extreme flood events will increase. A wetter future is characterised by an increase in high intensity, high frequency rainfall events. In South Africa areas along the east coast (Kwazulu-Natal and the Eastern Cape) become increasingly at risk from flood events. In the Western Cape, rainfall is projected to decrease in autumn, yet increase in winter and spring creating potential for seasonal floods.

An increase in flooding and intense rain will have significant impacts on infrastructure. Flooding will cause significant damage to both urban and rural societies. Already vulnerable informal settlements in rural, peri-urban and coastal areas will be particularly affected. In these areas infrastructure not designed to withstand increasingly high impact events will include homes, buildings, roads, railways and bridges. Social and economic losses are projected to increase as the intensity and frequency of extreme events continues. Recent experiences of flooding in South Africa give an indication of the hardships which will be faced (**Box 3**).

Box 3: Flooding severely impacts the poor in Limpopo Province

In January 2012 the northern provinces of South Africa were affected by flooding. Damages in Limpopo Province affected 200 families and infrastructure damages amounted to R21 million including fences, irrigation equipment, dams and store rooms.[21] Emerging and subsistence farmers were especially affected. Although budget was available for infrastructure rebuilding, the loss of crops could not be refunded.

Again, in 2013, flooding in Limpopo caused damages estimated at over R300 million to transport infrastructure such as roads and bridges, further exacerbating the backlogs which exist.[22] Similar deluges occurred in 2010, 2011 as well as more recently during the start of 2014, where the South African Defence Force was needed to assist with the search and rescue missions in both the Limpopo and Mpumalanga Provinces.[23]

21 SAPA, Hundreds of Limpopo families hit by floods, *Times Live* 20 January 2013. http://www.Timeslive.Co.Za/Local/2012/01/20/Hundreds-Of-Limpopo-Families-Hit-By-Floods

22 SAPA, Limpopo flood damage put at R300m, *News 24*, 12 February 2013 (online newspaper). http://www.news24.com/SouthAfrica/News/Limpopo-flood-damage-put-at-R300m-20130212

23 SAPA, Limpopo floods claim six lives, *Mail and Guardian*, 22 January 2013, (online newspaper). http://mg.co.za/article/2013-01-22-limpopo-floods-claim-six

Box 4: Peri-urban settlements susceptible to flooding

Graveyard Pond Settlement is frequently flooded. Imagery from 2007 clearly shows how the wetter region is uninhabited and remains wet for a number of months. Imagery from 2009 shows how the region has become inhabited.[24] The areas become inhabited out of desperation.

Graveyard Pond, September 2007 (left) and March 2009 (right) (City of Cape Town, 2008; 2010).

Standing water in a wetter and warming environment will negatively impact health. Rising temperatures and an increase in standing water create risk factors that amplify the potential for the spread of waterborne diseases such as cholera or dengue fever. In a wetter climate the potential for outbreaks increases as basic infrastructure is undermined and people are exposed to dense and possibly unsanitary conditions following an extreme event such as a major storm (**Box 4**).

Increased rainfall in a wetter world does not necessarily mean there is ample, clean water. High intensity rainfall events may result in increased erosion and siltation which has a negative effect on water quality and quantity. An increase in temperatures may also reduce the quality of water available (through increased microbiological activity for example). The reduction in water quality will result in an increase in water treatment costs for both rural and urban areas. In poorer, particularly rural, areas where there is limited infrastructure to treat poor quality water there will be significant health impacts.

In a wetter world, the above normal rainfall causes shifts in ecological resources. Biomes in their current form will shift as climate changes. High intensity

24 K Msungu, S Motala & J Smit, Using multi-criteria evaluation and GIS for flood risk analysis in informal settlements of Cape Town: The case of Graveyard Pond. *South African Journal of Geomatics*, 1:1, January 2012. http://www.sajg.org.za/index.php/sajg/article/view/27/11

rainfall events causing soil erosion have the potential to significantly degrade the quality of soil and plant cover. A warmer and wetter climate will be detrimental to the Fynbos biome of the Western Cape region for example, as there is high endemism with many species unable to survive under a different climate. In addition to the damages from flooding, the influx of "alien vegetation" under an "alien climate" is a significant risk to the biodiversity of the region. Without the climate under which fynbos is able to survive, ensuring the conservation of species becomes increasingly complex.

Rural livelihoods dependent on a stable climate will become increasingly vulnerable. Rural populations are especially vulnerable if they are reliant on the arrival of particular weather events. For example, subsistence farmers reliant on early rains for planting may be unable to achieve an adequate crop yield should the rains be delayed. Alternatively too much rain over a shorter period of time without storage will result in inadequate water supply during drier periods. Therefore, rural settlements without infrastructure to withstand climatic shifts (such as dams or rainwater harvesting) are particularly at risk.

The agricultural sector will shift as a result of changes in climate. Shifts in the timing and intensity of rainfall in South Africa will affect the growth and maturation of particular crop types. For example, in the Breede-Gouritz and Berg water management areas, a warmer and wetter climate will result in a decrease in autumn rain, but an increase in winter and spring rain. These shifts in rainfall will affect the yield and therefore the viability of deciduous fruits and viticulture in the area, while for some crops higher temperatures will result in an increase in water demand, which is not always met through increased rainfall.

Box 5: Citrus fruit exports to EU banned due to 'black spot'

In November 2013 the EU temporarily banned the export of citrus from South Africa in an attempt to stop the spread of the black spot fungal disease. The possible extension of the ban by the EU threatened the export from South Africa of 600 000 metric tonnes of oranges, lemons, limes and tangerines worth €1 billion. In the event measures taken by South Africa to control exports from areas affected by citrus black spot have staved off the ban. This has resulted in a drop in volume of citrus exports to the EU but higher prices in Europe have increased the value of exports. With shifting summer rainfall patterns, the incidence of black spot may increase or spread to previously unaffected areas.

In addition to crops, livestock may be negatively affected by increased rainfall through a higher likelihood of diseases such as hoof rot. The viability of a particular rangeland type (*Eragrostis curvula*) for grazing is projected to decrease in yield by approximately 10% in the northern and south-eastern regions of South Africa. This may result in a shift of livestock to more suitable grazing areas.

A wetter future also has a number of opportunities. These include an increase in rain-fed agriculture, for example. The opportunities for increased water need to be balanced against the increased risks of top-soil erosion, flood damage and increased occurrences of pests and disease for example.

Systemic adaptation responses

Early warning systems are required to promote proactive adaptive measures.

With increased risk of floods, EWSs become a crucial adaptation mechanism to improve responses to climate risks. Settlements, agriculture, health and transport are particular sectors which require innovation in improving their communication mechanisms. EWSs are needed both to collect information from community informants and share information to a range of levels from government, to community to individual households. In addition to the EWSs, adequate response management mechanisms need to be put in place and implemented. This is especially the case in a wetting future where transboundary watercourses in flood pose a risk to downstream communities.

Robust infrastructure is needed to withstand extreme events.

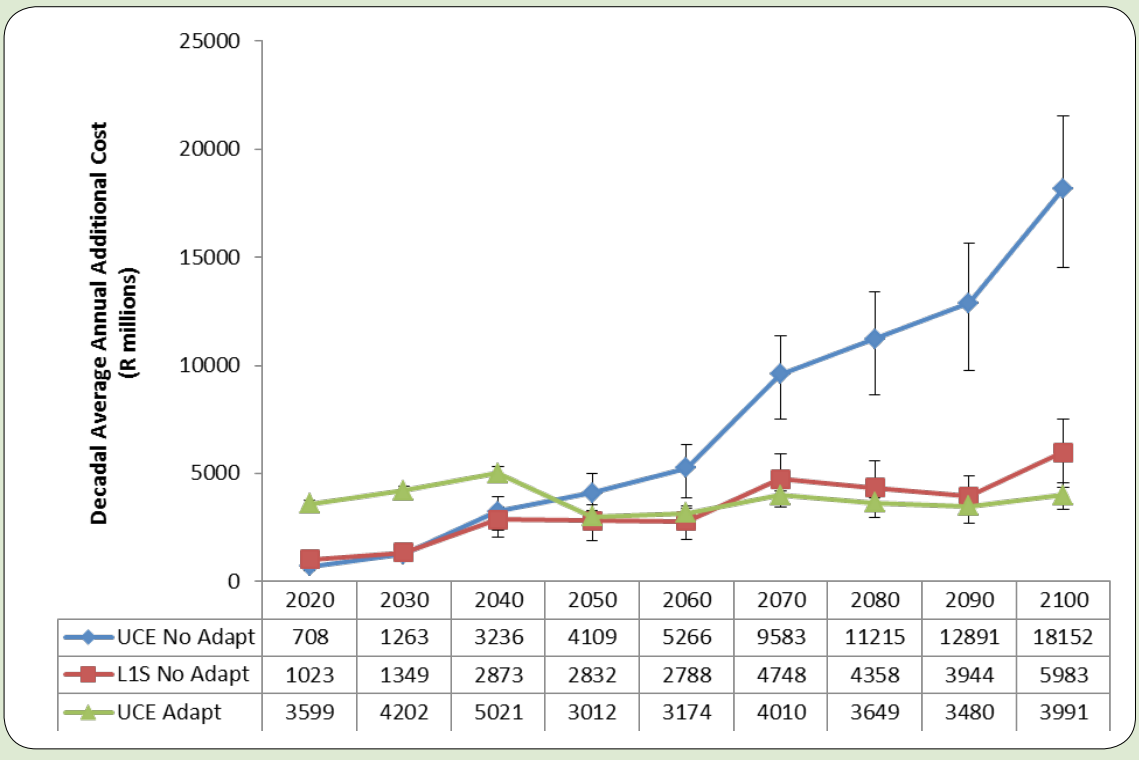
Under a wetter climate scenario, built infrastructure needs to be robust. Roads, bridges, railways and buildings need to be reassessed with respect to their construction and design codes in order to meet the new climate impacts (**Box 6**) and should be supported where possible by intact ecological infrastructure to help reduce climate impacts.

Box 6: Investments in road adaptation now will deliver net benefits in the future

The additional annual average cost for the no adapt scenario for South Africa's road infrastructure will increase dramatically from approximately R3 billion in 2020 to approximately R19 billion in 2100. When adapting, a higher initial cost will be incurred namely an additional R3 billion in 2020, however, the long term effect will be very beneficial. The LTAS Phase 2 economics study has found that by 2040 a break-even point is achieved. Beyond 2040, the costs for no adapt will increase dramatically in respect of cumulative annual costs to R19 billion in 2100.

The highest cumulative impact cost will be in the Eastern Cape Province of South Africa.[25]

The figure shows the median decadal average annual additional costs (R millions) on the roads infrastructure of South Africa for the adapt and no adapt management scenarios under the unconstrained emissions (UCE) and Level 1 Stabilisation (L1S) climate scenarios. Whiskers represent one standard deviation in the results for individual climate models.[26]



	2020	2030	2040	2050	2060	2070	2080	2090	2100
UCE No Adapt	708	1263	3236	4109	5266	9583	11215	12891	18152
L1S No Adapt	1023	1349	2873	2832	2788	4748	4358	3944	5983
UCE Adapt	3599	4202	5021	3012	3174	4010	3649	3480	3991

Figure 7: Median decadal average annual additional costs under different climate change scenarios.

25 DEA, Economics of Adaptation.

26 Ibid.

Flood resilient and socially sensitive settlement designs are crucial.

In a wetter climate future, informal and rural settlements are especially vulnerable to damage as a result of flooding and heavy rainfall. In urban areas, because of the density of people and infrastructure, transformative adaptation is especially required. In particular, defences against the failure of drinking water and sanitation provision are necessary to protect against the spread of diseases such as cholera and dysentery. The drainage of areas, such as storm water culverts needs to be adequate to reduce the ponding of stagnant water and resultant risk of diseases such as malaria. Transport infrastructure is also critical during times of disaster such as flooding. Urban areas need to be better integrated with transport to support mobility and economic development even under extreme climate events. Settlements with intact ecological infrastructure can also reduce the impacts of flooding.

Conservation management will change.

With an increasingly "alien" environment, sensitive species in particular regions may become extinct or shift as the area is no longer appropriate. Support for building or maintaining ecological infrastructure to maintain or enhance ecosystem services is critical. Innovative mechanisms to improve catchment management including, for example, incentives for sustainable land management, need to become mainstreamed in an effort to conserve their integrity.

Opportunities for agriculture may shift. The sector needs to be adaptive and innovative as regions suitable for agriculture change.

Adaptive responses from farmers in South Africa will include the shifting of crops and livestock to more suitable regions. Therefore, policies that hinder movement within the sector need to be reconsidered to support freer market movement. Technological responses may include investment in research into selective breeding of resilient livestock, wild crop species or GMO crops which are able to withstand damper conditions or related diseases.

4.4 Adaptation Scenario 3: A hotter climate in South Africa

Summary narrative

Mrs Mamabolo wakes up on the peri-urban fringe of Johannesburg. She walks to the bus station. As she walks she notices the changing plants and fauna along the fringes of the path – the landscape looks different from how she remembers it, drier and with fewer small flowers.

She wonders if, like her family home in the Drakensberg, where the grasslands have slowly been replaced by savannah, this change is happening all over the country. She remembers her sister telling her how, in Cape Town the fynbos is shrinking back and how some fear it will disappear from all but protected areas of Table Mountain by the end of the century.

Mrs Mamabolo boards the bus, it's hot and crowded. In the last two years the transport network has almost been overwhelmed as new migrants rush into Jozi pushed there by the droughts in Limpopo and other regions. In the heat the buses break down more often.

In the crowd she sees the faces of many different nationalities. She recognises a Mozambican family who have moved in next to her. She waves to them through the crowd. She feels sorry for them, they've been ostracised by the community who see them as a burden and as competition for scarce jobs. They arrived two months ago after fleeing their home in a small coastal village. After repeated storm surges life became difficult as the land was ruined by saltwater

Their daughter smiles back thinly; she's struggled with the heat in Jozi and is exhausted – often suffering from heat cramps. Because they're illegal immigrants, like many who have crossed into South Africa hoping to find safety from drought and benefit from a better life, they can't obtain healthcare.

The heat is certainly fearsome in Jozi and often 2–3 degrees higher than the surrounding areas. This has caused a partial exodus of the wealthy who, at the weekend, rush to air-conditioned villa's outside the city. Mamabolo remembers someone calling Jozi a heat-island and it certainly feels that way to her, especially when there are periodic water shortages.

Although water shortages happen occasionally, generally Mrs Mamabolo's thankful that she can now get water more easily in the morning, although she worries that the basics – water and food – are increasingly expensive. Each year the prices seem to rise and she's noticed recently

that the mealiemeal she buys to make pap looks different, yellower than before. When she turns the packet over at the store, shocked by the price, she sees it's imported.

As Mrs Mamabolo returns home the bus abruptly slams on the brakes and she is forced off the bus with the rest of its passengers who stand in the road looking up. She can see, some 300 meters down the road, thick smoke and flames whipping across the road. The adjacent township is on fire and people are pouring out onto the road – holding possessions and trying to escape the flames. Shack fires have become more frequent as the townships become drier than ever.

Scenario specific diagram

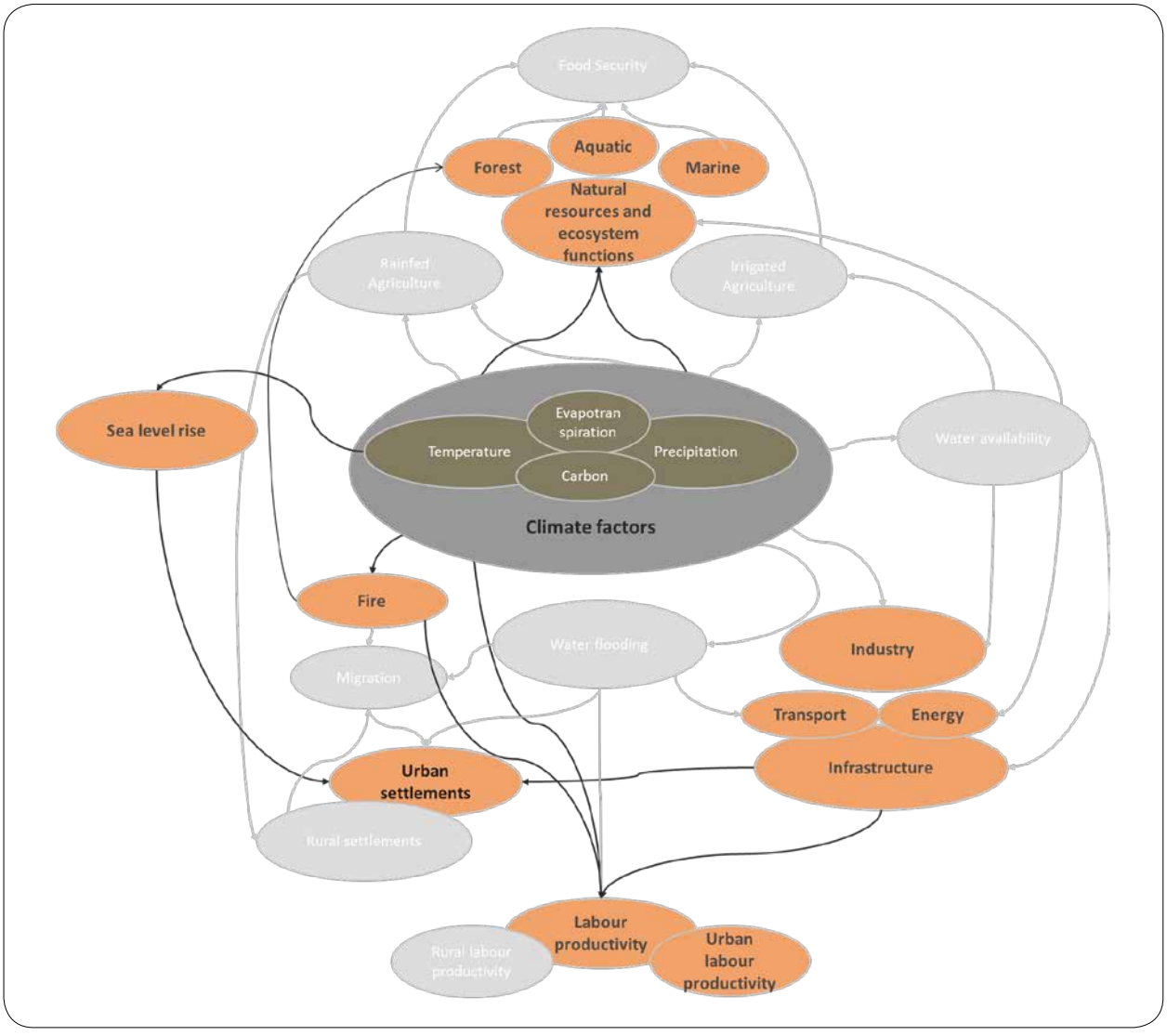


Figure 8: Systems diagram: A hotter climate in South Africa

Vulnerability assessment

In a hot scenario, we can expect temperatures to rise dramatically, by as much as 5–8°C in the interior of South Africa. Smaller, but still significant rises will occur on and around the coast. To put the magnitude of potential heating into context it's worth noting that all the changes that are attributed, with increasing certainty, to climate change (rising sea levels, heat waves, extreme storms, droughts and so on) have taken place within an average warming of the world's surface since the 19th century of less than one degree.

This temperature rise is compounded by the impacts highlighted in the wetter and drier scenarios beforehand. In this hot world extreme weather events increase in frequency and two climatically induced phenomena become increasingly relevant – sea level rise and fires.

In this scenario intense heat and the increasing incidence of extreme weather events mean people, flora and fauna are unable to cope. A large proportion of an already swelling urban population can no longer escape the heat. Labour productivity of all kinds, not just that in the rural areas suffers. This creates challenges for industries which experience direct physical challenges to their operations. Ecosystem and hydrological buffers break down.

Sea level rise

Rising sea levels and the increasing incidence of extreme storms will directly impact coastal cities and communities who rely on the sea for food and income. This includes ports and tourist destinations where significant economic assets will be at risk from inundation.

This could lower the productivity of estuarine fish habitats, particularly in KwaZulu-Natal and the West Coast. Estuaries are also the nursery sites for many important marine fish, and therefore the impacts are far-reaching for the fisheries and marine environment.

Uncertainty increases in a hotter world

Uncertainty over the impacts of climatic change is high under all scenarios. However insights from LTAS Phase 1 suggest that the degree of uncertainty increases significantly under a hotter scenario and that the volatility of climatic impacts could increase significantly.

This suggests that a hotter world would be one characterised by a fundamentally different and more extreme level of climatic volatility with (predominantly negative) implications for a host of economic and social realities in South Africa.

Box 7: Sea level rise impacts in Cape Town

In Cape Town a 2.5m rise (95% certainty in the next 25 years[27]) in sea level envisaged in Scenario 1 for the city will result in the loss of 1% of the area of the city (25km^2). Scenario 2 (85% certainty) sees 2% of the city's area (61 km^2) covered for short periods of time during large storms The loss of value in real estate for Scenario 1 equates to R3.25 billion over 25 years. The total cost to the City of Cape Town is estimated at R4.9 billion for Scenario 1 and R20.2 billion for Scenario 2, the latter figure equating to two-thirds of the city's entire budget for 2012/2013 (R30.3 billion).[28]

Figure 9: Projected areas of the Cape Town foreshore inundated under different climate change scenarios.

Wildfires

In a hotter scenario it is plausible that the frequency and intensity of fires will increase. In the Western Cape the impact is likely to be felt in the summer months while in the rest of the country fires will be more likely in the dry winter.

This could result in both an increased incidence of natural veld fires and shack fires in urban and peri-urban settlements. The negative impact of these fires will be widespread with the direct financial losses from property and infrastructure damage increasing.

While insufficiently researched, the implications of changing fire regimes for biodiversity are also likely to be significant. More precipitation and higher CO_2 levels with the resulting increase in fuel load are all likely to create changes to existing fire dynamics.

Aside from fires a hotter scenario will lead to serious risks to a number of South African biomes, principally the grasslands, where a shift to savannah is expected. The Nama-Karoo, which occupies the central plateau of the western half of the country, is the area where savannah and desert are expected to expand. Less than 1% of this biome is protected and without intervention it could be lost. The Indian Ocean Coastal belt and Fynbos biomes will also face risks in a hot climate and are projected to shrink. The contraction of these specific biomes will erode South Africa's natural capital base, undermine livelihoods and have implications for working landscapes, water use management, tourism and health.

27 Sea-level rise, Disaster Risk Management, City of Cape Town (web page). http://www.capetown.gov.za/en/DRM/Pages/Sea-evelRise.aspx

28 A Cartwright, Global Climate Change and Adaptation – A Sea-Level Rise Risk Assessment, City of Cape Town, June 2008. https://www.capetown.gov.za/en/EnvironmentalResourceManagement/publications/Documents/Phase%203%20-%20A%20Sea-Level%20Rise%20Risk%20Assessment%20(SLRRA).pdf

Box 8: Flying foxes dropping from the heat

Flying foxes are good bio-indicators of changing weather patterns due to their sensitivity to heat stress. Evidence of the extreme impacts of increasing temperature include the heat wave in February 2014 in Australia which caused the death of 45 000 flying foxes. This represents a 50% reduction in the flying fox population. The trend of extreme temperatures has caused similar deaths since 2008, and with temperatures projected to continue increasing, flying foxes face a dire future in Australia.[29]

Labour productivity

While some ambiguity remains over the impact of fire and warming on biodiversity there is little uncertainty about its negative impacts on health. Burns and smoke inhalation will contribute to increased mortality and morbidity.

While less immediately obvious, but potentially more significant, the labour force faces the likelihood of a general increase in discomfort. There is strong evidence to suggest that rising temperatures will have a substantial, and as yet under researched impact on labour force productivity. Indications are that daily productivity in the manufacturing sector could drop by 2% for each degree of warming.[30]

In the service sector and in high-value added sectors the response to temperature is non-linear, declining more rapidly on very hot days and in very hot months. In the South African economy, where temperature in a hot scenario could rise by 5–8 degrees and where 65% of the labour force works in the services sector, this impact would be significant even in urban areas. In the agricultural sector where the ability to manage high temperatures is limited, the implications are potentially ruinous and would necessitate a radical rethink of work patterns.

Infrastructure: transport, energy and manufacturing

In a hotter scenario the risk of extreme weather events increases. As a result, industrial operations in the mining, metals and secondary processing industries could be directly affected.

While direct impacts could be severe without adequate prevention, it is probable that the impact of extreme

29 J Wellbergen, C Booth & J Booth, Killer climate: tens of thousands of flying foxes dead in a day, *The Conversation*, 25 February 2014. http://theconversation.com/killer-climate-tens-of-thousands-of-flying-foxes-dead-in-a-day-23227

30 A Sudarshan & Meenu Tewari, The economic impacts of temperature on industrial productivity: Evidence from Indian manufacturing, Working paper 278, Indian Council for Research on International Economic Relations, 2014, p.1. http://icrier.org/pdf/working_paper_278.pdf

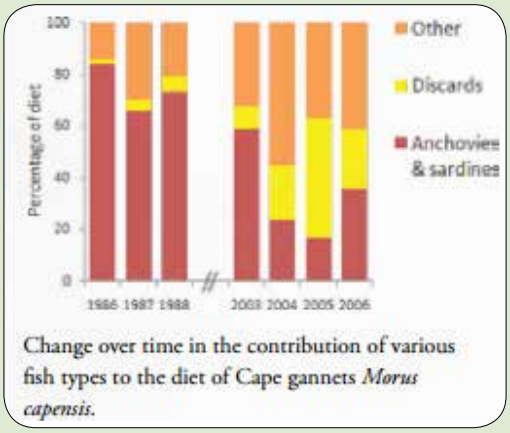
events beyond the factory gate via supply chains and employees could plausibly pose a greater strategic threat to industrial output. This is especially likely given the potential for commercial operations in profitable sectors to make autonomous decisions on adaptation measures and improvements to infrastructure tolerances.

However, the cost of adapting to a hotter world may create cost pressures that cannot be easily absorbed. In South Africa mining and large industry accounted for 8% (1.6 billion m^3) of total water use in 1996. In a drier world the cost of water, and the cost of ensuring its responsible management, can reasonably be assumed to increase substantially. The outlook for higher than average warming in southern Africa has the potential to create an additional input cost for South African industry, putting it at a disadvantage relative to international peers.

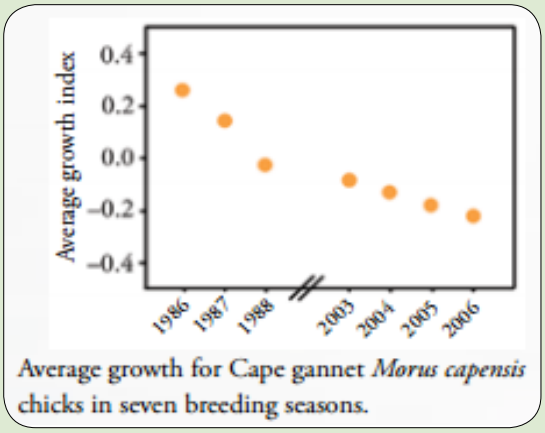
As discussed above, the implications of rising temperatures on workforce productivity are also likely to have a dramatic effect on competitiveness particularly in high-value added sectors. Conversely labour in less skilled sectors may face higher temperatures in situations where there is less ability to reduce the impacts on workers.

Box 9: Cape gannets threatened due to change in diet affected by ocean currents

Between 1997 and 2005, the number of Cape gannet breeding pairs has plummeted from 60 000 to 36 000. Evidence suggests that the decline is due to a shift in the distribution of the gannets' favoured food of anchovies and sardines resulting in the proportion of these fish in their diet dropping from 66–84% to 16–35%. The resulting shortfall in food is being met by low quality alternatives such as hake discards from shipping vessels. This poorer quality food intake affects the growth of gannet chicks, and this in turn affects their survival rate when leaving the nest.[31] The reduction in anchovies and sardines is believed to be linked to changing ocean currents as a result of global climatic shifts.



Change over time in the contribution of various fish types to the diet of Cape gannets *Morus capensis*.



Average growth for Cape gannet *Morus capensis* chicks in seven breeding seasons.

Figure 10: Change in distribution of food sources for Cape gannets and resulting decline in growth rate of chicks.

31 M De Villiers (ed.), Birds and environmental change: building an early warning system in South Africa, South African National Biodiversity Institute, 2009. http://www.adu.org.za/docs/climate_change_booklet.pdf

Systemic adaptation responses

Introduce early warning and response systems for fires, heat waves and storm surges

With a dramatic increase in the frequency and potentially in the magnitude of extreme weather events new institutional, technical and social responses will be needed. At national level new bodies will need to be created or existing agencies capacitated to take charge and manage the fallout from extreme weather events.

New emergency shelters will need to be created at regional and local levels to provide refuge for all kinds of extreme events. Technologies and approaches to making short term predictions of heat waves will need to be improved and effective ways to communicate quickly to citizens adopted.

Radically shift conservation mindsets

As average temperatures rise by above 5 degrees and rainfall patterns shift substantially, maintaining endemic species will become close to impossible in many regions. Conservationists will have to shift mindsets from a focus on maintaining the existing mosaic of flora and fauna to managing transition and prioritising resources in order to save the most intrinsically valuable species and ecosystems. Investing in ecological infrastructure, such as catchment areas which are critical for water production will be of utmost importance to maintain and conserve ecosystems.

Heat proofing urban design

As in the drier scenario, urbanisation can plausibly be expected to accelerate in a hotter world. This will require an overhaul in approach to both designing existing cities and providing services to stressed populations who arrive from increasingly uninhabitable rural areas.

However, while in a drier scenario cities are a refuge from the heat and lack of water, in a hotter world options become more limited. The urban heat island could amplify temperatures, reducing dramatically the productivity of manual and overall labour without serious interventions.

Urban design will need to refocus on providing respite from intense heat. Wasteful water consumption (swimming pools and golf courses), even for the wealthy, will be penalised. The impacts of heating and related impacts such as dust are likely to extend across income groups, although the greatest burden of the impact continues to fall on the poor. In this future specific adaption measures do exist to reduce discomfort. However, they will frequently be energy intensive (such as air conditioning) creating a risk that, in an energy constrained or decarbonising world, the costs of deploying such technologies will increase dramatically unless efforts are made to increase supply and/or deploy low-carbon power generation.

Changing environmental effects for South African labour

In a hotter scenario rising temperatures will effect where, when and how people work. While opportunities to improve working conditions through introducing new and existing technologies exist, the cost and energy demands may limit application.

In some regions of the country and in specific sectors new labour practices will need to be adopted and supported by appropriate legislation and measures to protect labour such as introducting a Mediterranean style siesta. In others a more dramatic shift of working hours to the morning and evenings may take place. In some instances arguably the working day will become shorter and productivity lower.

The shifting daily pattern of work regimes will have consequences for the locations and living conditions of labouring populations.

A strategic and comprehensive coastal management strategy

In light of rising sea levels it is probable that coastal areas of the country will face, if not inundation then more frequent and severe storm surges. In this scenario an active political decision will need to be made about the relative costs and benefits of a strategy that assumes all existing shoreline will be protected as opposed to considering the possibility of surrendering marginal areas of coastline.

Regional integration

In a hot world water availability is reduced. Extreme weather events could undermine power generation and agricultural production. Being able to access flexible regional power, water and food systems might increase South Africa's adaptive capacity. Constructive diplomatic relationships across Southern African Development Community (SADC) will support the region in effectively managing key issues such as migration, transboundary water sharing and energy management.

Resource centric national development planning

South Africa is unique in that it is the only country with a concentration of economic development that is not located either on the coast or on a major waterway. This situation has been addressed through a complex system of inter-basin water transfers that effectively move the critical resource to the area of need. This system has resulted in a certain level of resilience to both current and future climate variability. Climate change will not happen uniformly over the country and it is likely to stress the effectiveness of the current water resources infrastructure system, increasing costs and vulnerability. Resource availability will then become a major limitation for economic growth. Particularly under a hotter future it is critical that the availability of natural resources (including water, soil and biodiversity) be placed at the centre of national development planning. This requires new thinking and a mindset of moving the focus of development to the areas where natural resources are available and not the current thinking of moving resources to the existing areas of economic development, both in a physical and a "virtual" context. It will also require new mindsets on sub-national and regional integration to identify potential winners from climate change and mitigate the impacts on the losers.

5. RECOMMENDATIONS

When considering climate change adaptation responses, it is useful to consider planning and implementation over the short, medium and long term. These timeframes provide guidance on the relative urgency of response and identify no regrets adaptation options.

No and low regrets adaptation measures can be usefully implemented immediately. These will have benefits regardless of the direction of climate change projections. Closing the development gap and investing in ecological infrastructure are examples of shorter term, low regrets options.

Contingency planning for both wetter and drier climate futures is required in South Africa for the medium term. This would require a degree of overdesign in infrastructure which implies increases in upfront costs that may not yield benefits for years or even decades. For example, high capacity storm water drainage systems that are designed to cope with extreme events that may not happen in the short or medium term. This form of contingency planning is necessary to ensure vital systems are in place regardless of the climatic changes we experience, which to a degree remain uncertain. This approach would require a paradigm shift in approaches to optimisation and efficiency within government, and in all likelihood necessitate a national dialogue.

There is still a high degree of uncertainty whether South Africa faces a wetter or drier future overall, and how rainfall change will be distributed across the country. Projected changes in seasonal rainfall patterns also remain highly uncertain. Flexibility is therefore necessary to adapt to the uncertainty of the rainfall projections, both in the direction and rate of change, especially in current institutions and organisations.

Strategic policy recommendations

The following strategic policy recommendations are specifically short and medium term actions which require attention. The majority are no regret options which would help build the climate resilience of South Africa.

1. **South Africa's mitigation and adaptation negotiating position would benefit from integration and consideration of the way outcomes of the negotiations could impact the national and global economy**

In the context of the multilateral United Nations Framework Convention on Climate Change (UNFCCC) negotiations, South Africa would benefit optimally through a climate future that supports development aspirations, and a nationally appropriate mitigation response that has the same outcome.

It is clear from the LTAS work that failure to achieve the global mitigation goal defined by the Cancun Agreements significantly and progressively increases South Africa's risk of exposure to climate impacts and the associated adverse outcomes. Similarly failure of the South African government to adequately address climate change increases the country's exposure to risk.

It is potentially feasible to quantify much more concretely the social and economic costs and benefits associated with national mitigation actions, and the costs and benefits associated with climate impacts, adaptation responses and avoided damages. Such information would provide valuable strategic guidance in the context of the UNFCCC multilateral discussions. It would, therefore, be sensible to pursue this initiative nationally and sub-nationally, especially through the further refinement of the computable general equilibrium (CGE) modelling approach that is now used both in the context of national adaptation and mitigation responses.

2. **Implement robust and integrated monitoring systems to reduce uncertainty regarding climate change**

A monitoring programme that tracks changes in the South African climate and impacts on the natural and managed environment will help decision makers understand whether or not we are entering a drier or wetter future. Improved data collection can support attempts to track and model the rate of climate change.

A related, but distinct form of monitoring is also necessary to determine the effectiveness of adaptation measures. In both the monitoring programme that tracks climate and the implementation of adaptation responses, indicators need to be developed. These should inform a national monitoring and evaluation (M&E) system.

3. **Advance early warning systems to mitigate the projected increase of extreme events and support effective disaster risk reduction**

Improvement of the existing early warning system (EWS) and disaster risk reduction (DRR) approaches are necessary so that all sectors play a role in effective local disaster risk management. Research and development to support the improvement of existing EWSs, or the creation of novel predictive technologies should be bolstered. To target research and development efforts most effectively, an audit of existing public and private efforts could be undertaken.

Additional efforts should be made to ensure DRR is mainstreamed across sectors and at all levels of government. To support this enhanced capacity building and resource allocation is required and should be supported through implementation of the existing legislation (such as the Disaster Management Amendment Bill, 2015).

4. Improve understanding of the trade-offs in water allocation to promote sustainable and more economically effective water use

A more comprehensive understanding of national water use and the potential trade-offs is required. Existing legislation could support effective water management, but a greater focus on implementation is required.

In order to allocate water efficiently, water resources need to be maintained or enhanced through effective catchment management. Implementation of the revised water pricing policy and national water resource strategy is critical, in addition to good governance and adequate resource allocation to the catchment management agencies (CMAs) for implementation of their catchment management strategies. In addition to national water resource charges, local municipalities and the private sector can also play an important role in supporting effective catchment management.

Interbasin transfers (IBTs) have been shown to increase the resilience of water supply in South Africa. Vulnerable areas which are not supplied through IBTs, such as the Western Cape, should be addressed.

It is possible that the implications of water scarcity for energy production could also be significant. Further study is required to understand how different climatic futures could impact conventional and clean energy technologies.

5. Expand initiatives such as maintenance of ecological infrastructure to help to maintain, support and sustain livelihoods and ecosystem services

Initiatives such as ecosystem based adaptation (EBA) are becoming increasingly important, and are dependent on functioning ecological infrastructure. EBA includes a wide range of initiatives that will increase the adaptive capacity of livelihoods in addition to maintaining and restoring biodiversity and ecosystem services.

In addition to further expansion of EBA into existing legislation, other incentives to landowners and land users (across private and communal land) to improve natural resource management are required. Current initiatives such as the Expanded Public Works Programme (EPWP), land user incentives under the Natural Resource Management Unit and Strategic Infrastructure Programmes can support ecosystem based adaptation. Further efforts should be made to implement these initiatives to support enhanced resilience in both ecosystems and communities over the long term.

6. Mainstream climate resilience into urban, coastal and rural settlement design

Coastal settlement planning needs to increasingly focus on additional protection against rising sea levels and storm surges. Development by-laws require stricter implementation, and in some places reconsideration, in order to protect sensitive coastal zones and pre-empt damage. Leaving soft coastlines intact may be a means of protecting them against rising sea levels and storms.

The urban layout of settlements needs to be completely revisited. Climate-smart and socially sensitive urban designs are required to ensure vulnerable communities are not negatively impacted by extreme climate change events. Increased investment in climate-smart design, planning and building of infrastructure is necessary.

Rural settlements are especially sensitive to climate change due to their dependence on agriculture. To improve the resilience of rural settlements the rural economy needs to be rethought, especially under a drier and hotter scenario. Initiatives such as climate-smart agriculture (CSA) and EBA are important components of rethinking the economic function of rural areas. Urban and small-scale agriculture should be supported to play an increasingly important role in food security to build additional resilience.

7. **Understand trade-offs to ensure food security in South Africa**

In order to avoid undermining national food security, South African farmers need to be climate change resilient. CSA, which includes conservation agriculture, a focus on food security and adaptation and mitigation to climate change is one approach that may improve agricultural yields and domestic production whilst conserving ecosystem integrity.

Nationally, planners should consider the role of strategic food reserves and other approaches that can create buffers in times of drought and reduced food supply. This is especially relevant in a context in which South Africa's reliance on importing key commodities, such as staple crops, increases.

Options to increase food security may include expanding sustainable marine fisheries, importing staple food crops and integration into SADC regional agricultural markets as well as supporting access for small-scale farmers into these new or existing markets.

8. **Build robust infrastructure with an understanding of long term versus short term costs and benefits**

As climate impacts are projected to become more severe the approaches and protocols covering design and construction of infrastructure (such as building codes) need to be reconsidered and changes reflected in relevant legislation. Building tolerances may need to be increased and reviewed more frequently. Social, economic and environmental considerations need to be more closely integrated in the delivery of all infrastructure. This will be particularly important for implementation of all the strategic infrastructure programmes.

9. **Improve understanding of labour and capital flexibility in the economy**

A more flexible market for both labour and capital has the potential to help South Africa adapt to climate change by enabling a range of economic transitions to be made, which may be required in the face of climatic shifts. A better understanding of the way labour markets, and capital flows in South Africa are impacted by climate change is necessary to support effective policy interventions to increase flexibility. Further academic and industry studies are required.

10. **Increase education and capacity building as they are cornerstone adaptation responses necessary at all levels and in all sectors**

Skills training for adaptation needs to take place at national, provincial, local and community levels. In particular, local municipalities and community-based organisations and their beneficiaries need to be prioritised. The sharing of insights from processes such as long term adaptation scenarios (LTAS)s, as well as data generated need to be integrated within existing databases and toolkits for mainstreaming climate change at all levels.

11. **Coordinate all levels of government vertically and horizontally in the context of climate change**

Sectoral climate change response and adaptation plans need to be integrated across sectors with sufficient detail to provide an evidence base on which decisions over potential trade-offs can be made. Sub-national level detail is required to support implementation and to access adequate funding.

Local governments need support to build capacity to understand the options they have available to fund climate change responses and initiatives. Support is also

needed to help local government build adaptation into existing government processes. For example, support for building climate adaptation measures into the integrated development plans (IDPs) and providing support to help local government access finance to implement these IDPs effectively.

In some cases, where finance for climate change adaptation is available at national and local levels, the reporting of funded initiatives and examination of the impacts of such projects is poor and support should be provided to improve it.

12. Invest in further research into climatic impacts at local level and across industry value chains

The implications of both a dry and a wet climate future require further study both at national and local level. At local level further downscaled biophysical and econometric modelling will be required to inform appropriate adaptation response choices.

The implications of climate change for sectors, particularly key industry value chains needs to be further analysed, with particular focus on how local climatic impacts interface with globally integrated supply chains.

13. Explore innovative financing models to support delivery of appropriate adaptation responses

Accessing traditional sources of financing for conventional infrastructure is challenging. New funding models and sources will be needed to allow South Africa to raise appropriate finance for interventions, such as retrofitting existing infrastructure for adaptation.

14. Support integration of climate change considerations within national planning initiatives such as The National Development Plan

Delivering an appropriate response to climate change can help South Africa to deliver the bold and equitable vision laid out in the National Development Plan (NDP). To support this, efforts could be made to build a greater awareness of how climate change could impact the plan, especially with regard to cross-sectoral linkages and trade-offs.

Additional benefit could be realised by ensuring that all new central planning efforts, which may build on the framework established by the NDP, incorporate a climate change lens. This could help ensure that the risks posed by climate change are identified early and that plans are made to limit any detrimental impact.

Key to this is a change in mindset that places the availability and vulnerability of natural resources at the centre of national development planning and identifies ways to most effectively use the available resources in the face of future climate change impacts and uncertainty.

Research recommendations

Topic	Rationale and suggested focus for further research
1. Develop more robust and consistent tools for assessing climate change impacts and integrated economic cost/ benefit of adaptation in key sectors of the economy	The LTAS process has been limited somewhat by the application of distinct approaches among sectors to assessing the biophysical impacts of climate change. Also, very limited information is available for all sectors on costs and avoided damages due to adaptation measures. As a result it is challenging to develop a fully coherent view of priority areas for investment of resources into adaptation responses. A national effort to build this coherency would contribute to a critical strategic capacity for South Africa in prioritising adaptation investment. The development of a more comparable approach among sectors for projecting biophysical and economic impacts and avoided damages is a critical need. Ideally, these could be addressed by the development of a national and sub-national integrated assessment approach, and the use of a consistent range of future climate scenarios.
2. Build on the existing set of econometric tools for assessing integrated economic impacts of climate change across sectors in order to investigate alternative adaptation and development scenarios at national and sub-national levels.	Existing econometric models have been employed during the LTAS to explore the integrated impact of climate change across sectors, and to some extent these have been adapted using nationally developed sub-components of the model. These models and the results of initial analysis of the potential economic impacts of climate change are described in LTAS Report 6. Although these studies have considered a wide range of potential climate futures that encompass the four identified LTAS scenarios, they have not been used to model the potential impact of alternative adaptation and development scenarios. These tools should be used to investigate the alternative development and adaptation scenarios presented here. In addition further research is required to improve the individual components of the integrated models as well as more detailed investigations of the potential economic impacts for individual sectors or specific regions of the country that have been identified as being particularly vulnerable to future climate change impacts.

3. Drought and flood modelling	Provisional modelling of the potential impacts of climate change on droughts and floods has been undertaken during the LTAS programme and is presented in Report 3. These studies were, however, very limited in scope and further research is required to investigate a wider range of potential climate change impacts based on the most recent climate change scenarios developed for the LTAS programme. Flood modelling in particular requires more detailed analysis at specific locations including in urban areas, major road and railway bridges, power line river crossings and dams where changes in the design flood estimates could have significant economic impacts as well as increased risk of major disasters and loss of life.
4. Enhance approaches to modelling economically autonomous adaptation responses that are due to flexibility of labour and capital investment	Econometric models employed during LTAS to explore the impact of climate change have identified a key autonomous response via efficient reallocation of capital and labour in the South African economy. This is a strategically valuable insight. However, these models assume rapid and frictionless reallocations of labour and capital that represent highly flexible autonomous adaptation responses. These assumptions do not reflect accurately the resistance to such flexibility, due to inherent conservatism in the many actors involved, and other political economy issues that may increase the barriers to effective adaptation. It would be valuable to quantify the nature and extent of such flexibility revealed by the models, develop an ability to adjust this flexibility in the modelling tools and thereby assess the impacts in terms of reducing adaptive capacity, and identify policy interventions that might enhance this flexibility.
5. Improve the systematic production of climate projections and comparisons between different methodological approaches	When new climate projections are produced, these must be related to previous projections. It is important for users to understand what has changed in the assumptions used for the projections, and how this has affected the uncertainty or improved the credibility of the projections. It is also important for users to understand what has changed in the projections, and whether these changes are material relative to earlier projections.

6. Develop approaches for resource centric national development planning	Approaches need to be developed and tested for how the availability and vulnerability of natural resources can be placed at the centre of national development planning in order to maximise the potential benefit from these resources as they become increasingly stressed under future development and climate change. This is required in order to identify potential winners and to mitigate the impact on potential losers and to take into account sub-national and regional variability and the physical and virtual mobility of resources.

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Publishing date: March 2015

www.environment.gov.za