Western Cape Government
Environmental Affairs and Development Planning

BETTER TOGETHER.

THE ECONOMIC RISKS AND OPPORTUNITIES OF CLIMATE CHANGE RESILIENCE IN THE WESTERN CAPE

March 2018

DOCUMENT DESCRIPTION

Document Title and Version:

The Economic Risks and Opportunities of Climate Change Resilience in the Western Cape

Version 1: 19 March 2018

Author Information:

A. Cartwright – EconoLogic

N. Diederichs Mander – FutureWorks

M. Mander – FutureWorks

J.N. Blignaut – FutureWorks

J.H. van Heerden – University of Pretoria

J. du Toit – Vuna Agribusiness

I. Palmer – PDG

C. Mitchell – CM Consulting

Western Cape Government Project Management Team:

Sarah Birch, Frances van der Merwe, Lize Jennings-Boom, Goosain Isaacs, Western Cape Government, Department of Environmental Affairs and Development Planning, Climate Change Directorate.

Western Cape Government Contract Reference:

EADP3/2016

Document Copyright:

TABLE OF CONTENTS

FIGURES

TABLES

LIST OF ABBREVIATIONS

°C	Degrees Centigrade
BAU	Business as Usual
BRT	Bus Rapid Transit
CBA	Cost Benefit Analysis
CGE	Computable General Equilibrium (model)
CMP	Western Cape Coastal Management Programme (2016)
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties (UNFCCC)
CPI	Consumer Price Index
CPLC	Carbon Pricing Leadership Coalition
CSAG	Climate Systems Analysis Group
DRDLR	National Department of Rural Development and Land Reform
DEA	National Department of Environmental Affairs
DEA&DP	Western Cape Department of Environmental Affairs and Development Planning
DEDAT	Western Cape Department of Economic Development and Tourism
DOA	Western Cape Department of Agriculture
DWS	National Department of Water and Sanitation
EDP	Western Cape Economic Development Partnership
FAO	Food and Agriculture Organisation
GCEC	Global Commission on the Economy and Climate
GCM	General Circulation Model / Global Climate Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IAM	Integrated Assessment Model
IDP	Integrated Development Plan
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
LTAS	Long Term Adaptation Scenarios (of DEA, 2013)
M&E	Monitoring and Evaluation
Ml	Megalitre (1 million litres)
OECD	Organisation for Economic Co-operation and Development
PSC	Project Steering Committee
PV	Photovoltaic
SDGs	Sustainable Development Goals (of the United Nations, 2015)
SEZ	Special Economic Zone
SSP	Shared Socio-economic Pathways
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value-added Tax
WCCCRS	Western Cape Climate Change Response Strategy
WCG	Western Cape Government

KEY MESSAGES

CLIMATE CHANGE AND THE ECONOMY – STRATEGIC MESSAGES

Climate change is real, its impacts are being experienced now and future impacts are unavoidable. While the Western Cape Government cannot control the rate of global warming it does have the power to choose how to respond in order to manage local impacts. These choices will define the future growth or contraction of the Western Cape economy, will influence sectors of the economy benefit and suffer the most, and will determine the level of well-being of the Western Cape's people.

- Climate change will reconfigure economic competitiveness regionally and globally, but could also provide the catalyst for investment in climate adaptation that increases economic competitiveness of the Western Cape.
- While the private sector can be expected to adapt to protect their business interests, government has a role to play in protecting the public good and in sending clear signals to the private sector regarding the composition of the climate resilient local economy of the future. Effective investment in climate adaptation could result in climate change having a net positive economic impact in the province.
- Climate change and climate adaptation investment will not affect all sectors equally. Policy makers must balance the need to protect the most exposed sectors with the need to invest in the sectors that stand to benefit from climate change.
- Selecting which climate change responses to prioritise for implementation requires a nuanced understanding of the impact on each sector in the absence of public sector adaptation, and the cost benefit ratios of climate responses in respective sectors. While costs are easy to compare, the benefits of different responses may be very different in type, magnitude and timescale, and may affect some sectors of the population and economy more than others.

CHANGES IN PROVINCIAL GDP

By investing in improved climate resilience, the Western Cape economy could be 33% better-off in 2040 than if the province does not adapt to the impacts of climate change.

- The effectiveness of the Western Cape Government's climate adaptation policies, along with the reactions of other provinces, could significantly affect the extent of Provincial GDP growth or contraction by 2040.
- Failure to invest adequately in adapting to climate change could result in the Western Cape's GDP contracting by more than 17% by 2040, particularly if other provinces adapt more effectively.
- Effective investment in enhancing climate resilience could boost the province's GDP by more than 15% above the no-adaptation baseline by 2040, particularly where the Western Cape is a national climate adaptation leader.

- The greater the investment in climate resilience, the greater the benefits to the Western Cape economy.

CHANGES IN EMPLOYMENT

Employment levels in the Western Cape could increase by as much as 12.4% by 2040, if the province leads in adapting to climate change.

- Conversely, a failure to invest adequately in climate adaptation may result in employment levels declining by over 10% by 2040.
- Anticipating and meeting new skills and training needs in an expanding climate resilient economy in the Western Cape will be critical.
- Climate responses offer opportunities to create the type of local (and in some instanced low-skilled) work that unemployed people can access. A more inclusive climate resilient economy will be achieved through equipping the provincial workforce with the right skills to participate in it.

PRICE CHANGES

By becoming a national leader in climate resilience, the Western Cape can increase its competitive advantage and so limit price increases.

- Both climate change itself and investment in climate resilience, will affect the movement of people and the price of goods and services. This in turn will influence the relative cost of living, economic competitiveness, and social equality in different locations.

CHANGES IN TRADE

Regional exports from the Western Cape could increase by 6.4% by 2040 with enhanced climate resilience.

- In the immediate term Western Cape export competitiveness will depend on it adapting to climate change better than neighbouring provinces, regions and countries.
- In the longer term, the Western Cape needs other provinces and countries to adapt to climate change for there to be strong intra-regional and international trade and for the retention of market demand in spite of climate impacts.

IMPACT ON HOUSEHOLDS

A more climate resilient province will result in a lower cost of living and better quality of life for the Western Cape's people.

- Lower living costs resulting from more productive labour and investment in more efficient services is potentially a major driver of GDP growth in the province.

- Conversely, failure to invest adequately in adapting to climate change could lead to increased household cost of living in the Western Cape, with declining quality of life and a contracting GDP.
- The agriculture, water, electricity, transport and real estate services sectors affect household expenditure significantly, and should be prioritised for climate resilient investment.

CARBON PRICING IMPLICATIONS

Investment in climate resilience will secure the Western Cape's place in an increasingly carbon-constrained global economy.

- The Western Cape economy could be negatively affected by national or global carbon pricing, with the most exposed provincial sectors being petroleum refineries, and all electricity-intensive industries such as iron, steel and manufacturing.
- The Western Cape economy could benefit from increased demand for renewable energy stimulated by local or global carbon pricing, given the WCG's proactive stance in promoting the development of this sector.
- Proactive investment in the sectors that will benefit from a carbon tax would serve the strategic interests of the provincial economy and open new growth opportunities.

CLIMATE CHANGE IS MULTI-SECTORAL RESPONSIBILITY

Cost-effective climate change responses are being implemented across a wide range of Western Cape Government departments, highlighting that reducing climate change risks is a province-wide and multi-sectoral responsibility.

- The various economically attractive climate change responses that emerged from the Cost Benefit Analysis (CBA) included both adaptation and emissions mitigation actions, emphasising the importance of both.

INVESTING IN SYSTEMIC CLIMATE RESILIENCE CAN BE DIFFICULT TO ORGANISE, BUT OFFERS GOOD VALUE FOR MONEY

Many of the best performing climate change responses address the functioning of an entire social-technical or social-ecological system and produce multiple benefits.

- Climate change responses that offer work creation, developmental or ecological co-benefits are often economically attractive and cost effective.
- Some climate change responses actually reduce current expenditure by decreasing the purchase of electricity, water or other resources.

CBA SHOULD BE USED AS A DECISION-SUPPORT TOOL, NOT A DECISION-MAKING TOOL

Cost-benefit Analyses (CBA) provides a useful framework for comparing climate change investment options on the basis of "best bang for buck". However, in the climate change

context CBA seldom, fully reflects all costs and benefits, and the results will always require interpretation by decision-makers.

- Capital-intensive climate change responses may have poor cost to benefit ratios in a purely financial analysis but may impact positively on a significant percentage of the population. The high costs of these projects are sometimes justified for addressing specific climate change risks.
- Respective climate responses generate different suites of benefits over different time frames. Some may address immediate climate risks and others may deal with long-term resource security or greenhouse gas emissions reductions.
- Project costs and benefits can be separately viewed and ranked to provide specific insights for decision-makers.
- CBA models do not take decisions, and do not replace the responsibility and obligation on decision-makers to manage the difficult trade-offs in choosing which investments to pursue in reducing climate change risk and impacts.

1 INTRODUCTION

1.1 Global Climate Change and Sustainability

The Earth's near surface average air temperature is warming at 0.1°C - 0.25°C per decade (Kirtman *et al.* 2013; Haustein *et al.* 2016). In 2016, global average air temperature reached 1°C above pre-industrial levels (1850-1879) (Otto *et al.* 2015). This rise in Earth's average air temperatures has been described as "unequivocal" and "unprecedented over decades to millennia" (IPCC, 2014). In the scientific community, it is no longer contested that this warming is caused by the accumulation of greenhouse gases (GHGs) in the atmosphere (IPCC, 2014).

Global warming is not uniform. Many regions in South Africa, including some locations in the Western Cape, have experienced levels of warming above the global mean. South Africa's Provincial Climate Narratives, submitted to the United Nations Framework Convention on Climate Change (UNFCCC) at the end of 2016 as part of the country's Third National Communication, anticipate that the Western Cape will approach a 1.5°C average air temperature increase between 2040-2060, which is slightly ahead of the global mean.

There have been many economic assessments of the potential global cost of climate change. In their Fifth Assessment Report (IPCC, 2013), the IPCC estimated that a 2.5°C warming of the atmosphere above pre-industrial levels would cost the global economy the equivalent of losing between 0.2 and 2% of annual income, but admitted that such economic impacts are "difficult to estimate". The United Nations Development Programme (UNDP) has estimated that in 2010 climate change lowered global output by 1.6% of global GDP, equivalent to a loss of $1.2 trillion; and with the growing rate of climate change impacts, average global economic loss could rise to 3.2% annually by 2030 and up to 10% per annum by 2100 (UNDP, 2016). A UNEP report looking at the same timeframe estimates that the cost of adapting to climate change could be as much as US$280 – US$500 billion per annum by 2050 (UNEP, 2016). It is widely recognised that a disproportionate burden of these costs will be carried by poor people in the form of higher food prices and exposure to environmental catastrophes (Rozenberg and Hallegatte, 2015).

In response to this threat, signatories to the UNFCCC's Paris Agreement in 2015 committed to curtailing global warming to "well below 2°C", and to "explore efforts to limit warming to 1.5°C". This is an ambitious target, especially given the embedded warming commitment from inertia in the physical Earth system that will add 0.3°C once emissions have stabilised (Collins *et al.* 2013). Technological, economic, institutional and behavioural inertia is also likely to add an additional 0.2°C-0.5°C on 2015 levels (Pfeiffer *et al.* 2016; Seto *et al.* 2016).

The Paris Agreement was, however, marked by a widespread commitment from Nation States (including South Africa), regions and cities to tackle climate change. This commitment arose not only from the imperative of avoiding catastrophic damage, but also from the idea that mobilising a global response to climate change could create economic and development opportunities (GCEC, 2014).

To achieve the Paris Agreement, an estimated $16.5 trillion will have to be invested or reallocated towards renewable energy, sustainable cities, public transport, and adaptation and resilience building by 2030 (Standard and Poors, 2016). This reallocation of global capital will generate new economic opportunities, some of which developing countries will be well-placed to benefit from. This could go a long way towards assisting these countries implement the United Nations Sustainable Development Goals[1] (SDGs), particularly through unlocking the synergies between climate action (SDG 13), poverty eradication (SDG 1), universal access to energy (SDG 7), responsible consumption and production (SDG 12), and sustainable cities (SDG 11).

1.2 Leveraging an Economic Transition

The understanding that climate change has its origins in economic activity and will have economic impacts is not new. Successive reports have attempted to aggregate the cost of environmental disasters, increased uncertainty, migration and the need to re-invest in a 'low carbon'[2] economy (Nordhaus, 2001; Stern, 2014; Tol, 2009).

Land use changes and the combustion of fossil fuels for energy generation, transport and industrial processes (including cement manufacturing) are responsible for most carbon emissions. These activities are also fundamental to the way the global economy has grown over the past 150 years.

It was only when the economic model that had driven growth in OECD[3] countries began to falter in the wake of the 2008 financial crisis, and when the costs imposed by climate change-related disasters began to accumulate, that a consideration of alternative economic models began to emerge. The hope is that an economic growth path that minimises climate change risks and prioritises low carbon sectors and strategies can offer a better, if not the only viable, means of ensuring future growth (UNEP, 2011; OECD, 2011).

Change has proven more difficult than anticipated. Markets, left to their own devices, have not been able to deliver the required low-carbon growth path. Carbon emissions are embedded in economic activity and the global economic systems that have evolved over many years. These systems are difficult to dismantle. With few exceptions, individuals, households, companies and governments have struggled to forego the immediate economic benefits of using fossil fuels to avert the increasing costs of climate change.

Understanding greenhouse gas emissions as an "economic externality"[4] and a form of market failure, presents a clear case for government intervention. This intervention is becoming easier as awareness mounts and new cleaner technologies evolve, and some

[1] http://www.un.org/sustainabledevelopment/sustainable-development-goals/

[2] The term 'low carbon' is used in this document to infer low levels of greenhouse gas emissions.

[3] The Organisation for Economic Cooperation and Development (OECD) promotes policies that improve the economic and social well-being of people around the world. While not a member, South Africa is a key partner of the OECD, contributing to the OECD's work in a comprehensive and sustained manner.

[4] The basic premise of the greenhouse gas emissions externality is that those who produce emissions do not pay for them, and those that are harmed by emissions are not compensated.

precedents for decoupled emissions and economic growth already exist. The United Kingdom has grown its economy by 60% over the past three decades, while simultaneously reducing its emissions by 40%, primarily through a switch to natural gas as an energy feedstock. China has reduced the carbon intensity of its GDP from 6.1 kilograms per 2010 US$ of GDP in 1960 to 1.3 kilograms per 2010 US$ of GDP in 2013, while simultaneously becoming an economic superpower[5].

The idea that climate change could reconfigure global competitive advantage is particularly attractive to African countries, which have frequently suffered from weak bargaining positions in the integrated global economy. There is the related hope that low carbon energy technologies, waste handling and climate smart agriculture will mobilise new sources of funding and offer much needed opportunities for development. That climate change will create new economic 'winners and losers' across sectors and regions is a compelling idea. Unless understood in detail, it may also be fanciful, and is certainly not guaranteed (Pelling *et al.* forthcoming). It may transpire that the same underlying lack of income, infrastructure and capacity that leave African economies under-developed will be exposed by climate change, and that the inequality that is a definitive feature of the Western Cape economy, for example, may be exacerbated by climate change impacts.

The difference between the historical perspective of climate change as an economic burden and climate change as an opportunity is likely to depend on public sector leadership and partnerships between spheres of government, and between government, the private sector and communities. The Western Cape Government (WCG), with the City of Cape Town, has been internationally recognised for its partnerships and capacity in responding to climate change (Cartwright *et al.* 2013; Taylor *et al.* 2014) and officially aspires to achieve a low carbon economy and become the 'green economy hub' for the African continent (WCG, 2013a). The Western Cape cabinet has endorsed the 'Western Cape Climate Change Response Strategy (WCCCRS) 2014' and an Implementation Framework, and Monitoring and Evaluation (M&E) report which coordinates the climate change response for the province. The WCCCRS 2014 aims to guide the implementation of innovative projects and the search for opportunities that combine a low carbon development trajectory with increased climate resilience, enhancement of ecosystems and the services they provide, and economic stability and growth.

The technologies and precedents through which climate resilient, low carbon growth can be pursued are increasingly available and affordable. There are, however, still very few precedents indicating how the benefits can be scaled across the economy, or how the tricky transition from the Western Cape's current dependence on coal, private vehicle road transport and spatially sprawled development might be managed. However, the environmental and humanitarian prerogative of effective climate change adaptation and the transition to a low carbon economy will only be met in the Western Cape if public and private investment is aligned behind the goal, if utility and regulatory pricing factors are integrated in the social cost of carbon, and if climate change itself is recognised as an

[5] https://data.worldbank.org/indicator/EN.ATM.CO2E.PP.GD

economic risk and opportunity - and not simply the exclusive domain of environmental departments and conservationists.

1.3 The Focus of the Study

The WCG has recognised the risks posed by climate change to its economy, population, ecosystems and infrastructure. These risks are already being experienced as escalating costs to the public and private sector for remediation and repair of damage resulting from more frequent and intense storms, floods, droughts and wildfires. Critically for the Western Cape, climate change is predicted to compound these pressures not only on environmental systems, but on social and economic systems too, escalating social inequality due to the disproportionately high impacts on the poor and their limited capacity to adapt.

As described in several key Western Cape policy documents (including the Western Cape Climate Change Response Strategy, 2014), the need to address vulnerability and build resilience in response to climate change risks offers an unprecedented opportunity to direct investment in a manner that accelerates the process of transitioning the Western Cape economy, cities and society towards a more just, equitable and sustainable future. The challenges, however, are where to begin and how to prioritise climate adaptation action across a diverse range of impacts, vulnerabilities and risks.

The WCG commissioned the "Assessment of Economic Risks and Opportunities of Climate Resilient Investment" study to evaluate the economic costs of climate change and the potential economic benefits of investing in climate resilience. The study seeks to generate information that can assist the WCG in directing investment towards climate change responses that reduce climate change related risks and increase resilience to increased short-term climate variability and long-term change, while simultaneously driving inclusive economic growth and development.

The study comprised two key economic modelling components:

1. An economic modelling process using a static Computable General Equilibrium (CGE) model to determine the impacts of climate change and climate adaptation investments on the economy of the Western Cape province. This modelling uses a series of expert-derived climate change impact and climate adaptation scenarios to 'shock' the CGE model and so produce a series of future economic scenarios for the Western Cape.

2. A Cost Benefit Analysis (CBA) to prioritise Western Cape climate response measures based on best economic and social outcomes for lowest financial cost. The CBA will use both traditional financial methods as well as a people and development focused 'Human Benefit Index' approach to identify the non-financial social costs and benefits associated with different adaptation options.

As per the two bullet points above, the assessment of economic risks and opportunities of climate change resilience in the Western Cape has required an analysis at two levels. Firstly, an analysis of the macro-economic implications of investing or not investing in climate change resilience was required to understand the direction and magnitude of economic changes that could be associated with investing in climate change resilience or not. Secondly, a detailed CBA of a selection of climate change responses was required to understand which types of interventions were the most economically efficient, and which of these interventions were most beneficial to society. The two analyses together are able to show the economic implications of climate change responses, to inform the WCG economic strategy and to inform the development or updating of climate response strategies and actions.

The methodology employed, the process followed and the findings are presented in this report.

2 MODELLING ECONOMIC SECTORS AT RISK AND IMPACT UNDER FUTURE CLIMATE CHANGE SCENARIOS

2.1 The Economic Modelling Approach

The economics of climate change rests on two key assumptions:

(i) global economic progress has occurred at a time of relative climatic stability, and

(ii) the bulk of current economic activity relies either directly or indirectly on the burning of fossil fuels, or the extraction of organic carbon from the soil or plants, which results in accelerated releases of greenhouse gases into the Earth's atmosphere.

Consequently, climate change is considered a direct result of the economic progress achieved globally through using fossil fuels as a primary energy source and the conversion of biosphere carbon into atmospheric CO_2.

Once climate change is understood as an economic issue, a link can be drawn between what happens to the climate and changes in economic behaviour. Integrated Assessment Models (IAMs) are used to model these linkages over time.

IAMs, the basic architecture of which is represented in **Error! Reference source not found.**, make assumptions about the extent of climate change that is likely[6], and how people and governments will respond to climate change through their economic preferences and policies. Typically, these assumptions are grouped into a set of scenarios. The IPCC's scenarios are called Shared Socio-economic Pathways (SSPs) and capture different assumptions on regional co-operation, population growth, rates of urbanisation and economic and technological progress, among others. Projections are made based on the historical data between parameters, physical laws of energy transfer, and modelled economic relationships. IAMs divide the world up into regions that interact with each other through trade, migration and investment. William Nordhaus, at Yale University, developed the DICE IAM – the Dynamic Integrated Model of Climate and Economy - to understand the implications of different climate policies on the global economy.

In 2006, Nicholas Stern produced the Stern Review, possibly the best known economic assessment of climate change. Stern and his colleagues relied on an IAM for this study. The parameterisation of IAMs, however, is a source of controversy, with many researchers feeling they fail to capture the complexity of climate-economy relationships (Dietz, 2009).

---

[6] To determine the extent of likely changes in climate, climate models are used. These aim to capture the statistical average of temperature, wind, cloudiness and precipitation over time. Global Circulation Models (GCMs) represent a specific type of climate model, and seek to represent the interactions between atmosphere and oceans. Understanding what happens to GCMs as atmospheric greenhouse gases increase has been a major focus of climate change science over the past three decades. The Hadley Centre in the United Kingdom and the National Climate Data Centre have both compiled significant GCMs. In South Africa, the Climate Systems Analysis Group has downscaled the Hadley Centre models to provide local climate projections.

Stern himself lamented the limitations of IAMs in 2016, saying: "*Sadly, most IAMs struggle to incorporate the scale of the scientific risks, such as the thawing of permafrost, release of methane, and other potential tipping points. Furthermore, many of the largest potential impacts are omitted, such as widespread conflict as a result of large-scale human migration to escape the worst-affected areas*" (Stern 2016).

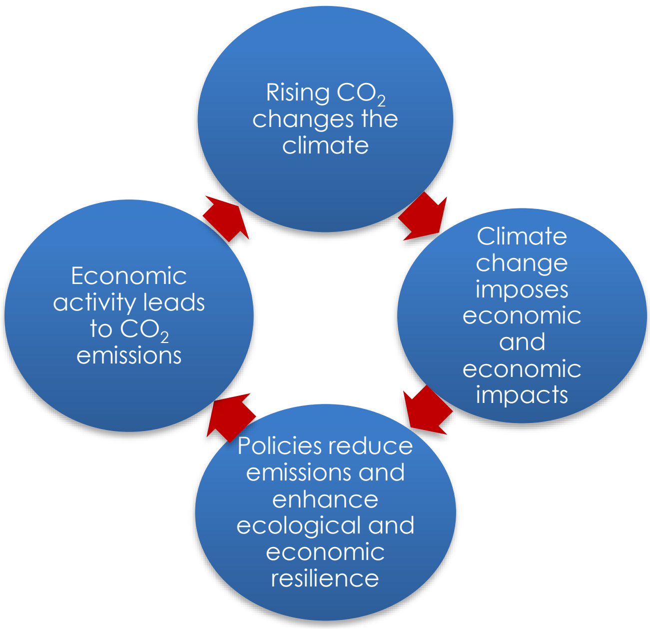

Figure 1: The climate-economy interaction that is evaluated in most Integrated Assessment Models (adapted from Nordhaus, 2013)

Given the complexities associated with IAMs, the study that has been completed for the WCG and reported on here has rather used a Computable General Equilibrium (CGE) model. CGE models do not capture the interaction between biophysical and economic changes, and instead focus on describing the dynamic relationships between sectors in the economy. CGE models are used to assesses how changes in some sectors affect others, and the economy as a whole.

CGE models also differ from conventional IAMs in that they can be used to evaluate how economic and climate change policies could impact the economy either positively or negatively (Figure 2). This is in line with new research suggesting that, especially in developing countries, climate change could provide the catalyst to new investment and better economic development (GCEC, 2014).

The CGE modelling reported on here focused on how different levels of investment in enhancing climate resilience would impact the provincial economy either positively or negatively, under conditions of either high or low climate change impact. Had an IAM been used, greater focus would have been given to how changes in climate would have impacted the economy, rather than changes in investment.

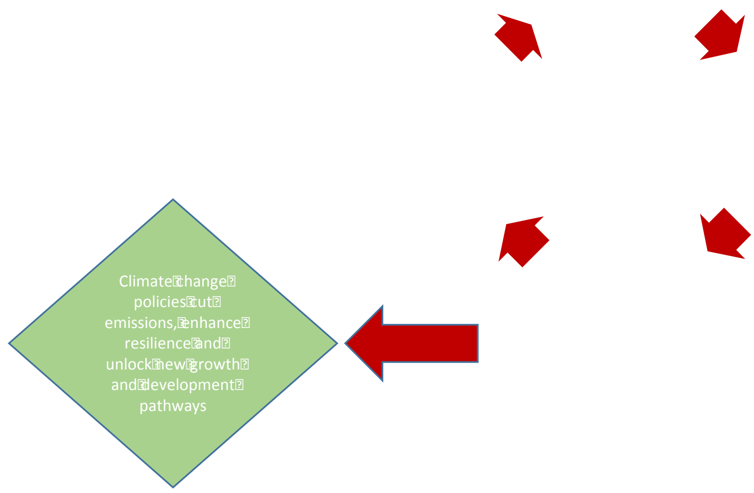

Figure 2: The CGE modelling used in the study recognises the relationship between the economy and the climate that is assumed by most IAMs, but includes the possibility that effective policy responses to climate change could cut emissions, enhance climate resilience and stimulate economic growth

2.2 Methodology

2.2.1 The use of a CGE Model

The study has used the University of Pretoria's regional Computable General Equilibrium (CGE) model. This type of model can be used to evaluate the interactions between all role players in the economy, namely all industries, consumer groups, national and regional governments, and the foreign sector. It starts with an economy which is characterised by an equilibrium in all markets (supply equals demand), as depicted in the Supply-Use Tables of Statistics South Africa in any given year. The modelling process involves manually changing the values of one or more exogenous variables (representing changing in the economy – normally capital stocks in one or more economic sectors) and then allowing the computer to search for a new general equilibrium in all markets.

The model is not an econometric model that uses time-series data. There are too many role players in the economy to have enough data for all of them for each year of modelling simulation. Rather, the starting point is a snapshot of the economy in a given year, and the end point is a snapshot of the economy at some future date once certain changes in the economy have been assumed, and the model has brought the markets back into equilibrium. The two snapshots are compared, and the reasons for the changes are interpreted.

The University of Pretoria's CGE model was also recently used in a major World Bank study for the National Treasury to calculate the economy-wide effects of the proposed national carbon tax[7]. The model has also been used in a study funded by the Dutch government to search for triple dividends from a carbon tax with appropriate recycling of tax revenue[8].

The University of Pretoria's CGE model contains 27 economic sectors / industry clusters, the data for which is disaggregated per province and sourced from Statistics South Africa. These sectors include:

1. Agriculture: all agricultural production
2. Coal: coal & lignite mining
3. Gold: gold, uranium & metal ore mining
4. Other mining: other mining & quarrying
5. Food & beverages manufacturing
6. Textiles & footwear manufacturing
7. Wood & paper products manufacturing
8. Petrochemical products manufacturing
9. Glass & non-metal: manufacturing of glass & glass products, & non-metallic mineral products
10. Metal & machinery: manufacturing of basic iron & steel, precious metals, non-ferrous metals, structural metal products & general-purpose machinery manufacturing
11. Electrical manufacturing: manufacturing of electrical machinery & apparatus
12. Radio & TV: manufacturing of electronic valves, tubes, other electric components; Radio & TV transmitters, apparatus for line telegraphy; and Radio & TV receivers, sound or video recording or reproducing apparatus and associated goods; manufacture or medical appliances, optical instruments, photographic equipment and watches and clocks.
13. Transport equipment: manufacturing of motor vehicles, locomotives, aircraft, spacecraft, ships and boats, as well as motor vehicle engine parts and accessories
14. Other manufacturing
15. Electricity supply
16. Water services: collection, purification & distribution of water
17. Construction
18. Wholesale & retail trade services
19. Hotels & restaurants
20. Transport services: land, water & air transport services; supporting & auxiliary transport activities, travel agencies
21. Post & telecommunications services
22. Financial services: all financial services, including pension funding & insurance
23. Real estate services

---

[7] See Van Heerden, J., Blignaut, J., Bohlmann, H., Cartwright., A., Diederichs, N. and Mander, M., 2016. The economic and environmental effects of a carbon tax in South Africa: A dynamic CGE modelling approach. *South African Journal of Economic and Management Sciences,* Vol 19(5), pp 714-732.
[8] See van Heerden, JH, Gerlagh, R, Blignaut, JN, Horridge, M, Hess, S, Mabugu, R, and Mabugu, M,. (2006). Searching for Triple Dividends in South Africa: Fighting CO_2 pollution and poverty while promoting growth, *The Energy Journal,* Vol. 27, No. 2, pp. 113-141.

24. Business services: research & development, computer & related activities, renting of machinery & equipment
25. General government services, including education
26. Health & social services
27. Other services

The CGE model starts at a point where supply is equal to demand in every sector and where the government's budget is balanced. This starting point is called T0, and in the current modelling exercise is assumed to be the year 2016.

To model the impact of climate change and climate resilient investment, the CGE model is "shocked" by changing the capital stocks in the different provinces and different industries in accordance with climate change impacts, as anticipated by sector experts. The resulting changes in the economy that would be necessary to achieve a new equilibrium are then studied. The new equilibrium is reached through all commodity and factor prices being changed until supply is again equal to demand in each market. Hence the "computable" part in the name of the CGE model: the computer uses a complex algorithm to search for a set of prices in all markets that would bring the economy back into to equilibrium after having been perturbed.

In the current modelling exercise, the new point of equilibrium is assumed to be in the year 2040. This year is called T1 in the model, and thus the modelling is undertaken to estimate changes in the economy in the 24-year period from 2016 to 2040 (T0 to T1).

The percentage changes presented in the results section of this report reflect the difference in sector sizes before and after the climate shock has been imposed, and once all prices have adjusted. The model assumes that it is the relative change in a variable, i.e. the "after" values relative to the "before" values, that is of interest - rather than the absolute value of a variable.

The modelling process involved the following five steps:

1. Selection of economic sectors to use in the modelling;
2. Defining the nature and scale of climatic change in the Western Cape;
3. Defining future scenarios and associated assumptions;
4. Modelling the future scenarios;
5. Analysis of the results.

These five steps are explained in the sections which follow.

2.2.2 Selection of economic sectors to use in the modelling

Five economic sectors in the Western Cape province were selected for detailed study in the CGE modelling process. It is these sectors that have been perturbed in the CGE model to simulate the impact of climate change on the province-wide economy (i.e. all 27 sectors that are included in the CGE model). The expected changes in investment that would take place in these sectors with climate change and climate resilient investment was used as a proxy for investment changes in the whole Western Cape economy with climate change.

The five priority sectors included:

1. Water;
2. Energy;
3. Agriculture;
4. Transport; and
5. Construction.

These were selected based on one or more of the following criteria:

- Sectors that are important in the Western Cape economy, the City of Cape Town (the only metropolitan municipality in the province), or are considered important for future economic growth in the region (City of Cape Town, 2015, 2016; WCG, 2012b, 2013a, 2014a);

- Sectors that are known to be vulnerable to climate change (for example agriculture), or present specific opportunities for mitigating climate change (for example energy) (DRDLR, 2013; DWS, 2014; WCG 2016a,b; WCG, 2015; WCG, 2014b);

- Sectors for which appropriate data are available and in which the WCG has existing climate change initiatives (City of Cape Town, 2015, 2016; DWS, 2014; WCG 2016a,b,c; WCG, 2015; WCG, 2014b; WCG, 2013a,b,c; WCG 2012a,b).

The choice of the 'construction sector' was deliberate in that it serves as an indicator for investment (both public and private) in infrastructure and buildings, including those that may be damaged by climate change or are required to manage climate change impacts.

2.2.3 Defining the nature and scale of climatic change in the Western Cape

Based on weather readings, the Western Cape has been affected by the general warming trend that has been reported globally by the Intergovernmental Panel on Climate Change (IPCC, 2013). Between 1960 and 2012, the following has been observed (WCG, 2016c):

- Significant parts of the Western Cape warmed at a rate that is almost double that of the global mean;
- There have been significant increases in hot extremes, most notably in the Western Cape interior;
- The rainfall seasonality has shifted and while no significant trend in the mean rainfall is discernible, rainfall events appear to have become more intense.
- The frequency of dry spells has increased, and the Autumn months have become significantly drier. There are some climate models that expect the Western Cape to become significantly drier based on a poleward shift of weather bands, but this is not a consensus view yet;
- Observed sea-levels appear to be increasing in line with the global mean. An annual rise of 1.7mm was observed each year between 1901 and 2010, and an accelerated rise of 3.2mm was observed each year between 1993 and 2010. The data are poor, but Mather *et al.* (2009) suggest that the rate of eustatic sea-level rise along South

Africa's southwest and southern coast has been 1.57mm per annum since the late 1950's.

South Africa, and particularly the Western Cape province, is fortunate to have some of the continent's most sophisticated climate modellers providing a catalogue of research from which to speculate about how anthropogenic climate change will affect regional weather patterns in the future. The Climate Systems Analysis Group (CSAG), based at the University of Cape Town, has contributed toward the preparation of South Africa's biennial National Communications to the UNFCCC, which covers predicted changes in climate, and disaggregated climate projections for each of South Africa's provinces[9]. To undertake this work, CSAG uses a suite of "downscaled" general circulation models or global climate models (GCMs) that forecast future climates for the region in which the Western Cape falls. Downscales take place *via* two distinct methods:

- Dynamic downscales, where local micro-climatic conditions (such as the influence of topography) are added to drive the outputs of GCMs at a higher spatial resolution.
- Statistical downscales, that apply the statistical relationship between macro-components of the GCM (such as atmospheric pressure) and local weather data to make forecasts.

Neither method provides a perfect predictor of future climate and in general the finer the spatial resolution at which a climate forecast is required, the greater the uncertainty over the prediction. In the Western Cape, this is particularly difficult as the province includes both Winter and Summer rainfall regions, exposure to both the cold Atlantic and warm Indian Ocean, and a mountainous topography, all of which introduce considerable variability that confounds accurate forecasts. For example, the province's coastal mountain ranges receive as much as 1,500mm of rain *per annum*, while regions within the dryer interior, such as around the town of Laingsburg, only receive 120mm *per annum*. To reduce this uncertainty, climate modellers tend to run multiple iterations of different downscaled models to produce an "envelope" of potential future climates.

By comparing the model predictions for the Western Cape with measured changes in actual weather over the past four decades, the modellers are also able to familiarise themselves with the relative strengths and weaknesses of the downscaled models they are using. These limitations include that:

- There is no statistically significant rainfall trend over the past 86 years, relative to historical variability in rainfall.
- Actual temperature changes up until 2000 were not as severe as those predicted by the models.
- Observed seasonal changes in Autumn and Spring rain are not predicted by the models.

---

[9] In late 2016, the National Department of Environmental Affairs submitted South Africa's Third National Communication to the UNFCCC.

- The models do a much better job of capturing temperature change than rainfall change.

Despite their limitations, the models show with a reasonable degree of certainty that residents of the Western Cape should expect (CSAG, 2016):

- Temperatures to increase by more than 2°C by 2100, with all models showing an increase of more than 1.5°C. One Western Cape model anticipates temperature increases of 1.5°C by 2040-2060;
- A possible increase in the frequency and length of hot spells in Summer, as well as a decrease in the frequency and duration of cold spells in Winter;
- More intense subtropical high-pressure systems combined with more intense inland heating, causing stronger Summer winds from the southeast;
- Higher wind speeds combined with higher temperatures, increasing evapotranspiration and plant stress, and reducing water run-off;
- Significantly longer and more frequent dry spells towards the end of the 2040-2060 window.

While temperature rises would cease within a decade of increasing emissions shifting to zero, sea-level rise would persist for as much as a century, and the rate of SLR has increased dramatically in the past two decades. The downscaled GCM models do not pronounce on sea-level rise. However, drawing on the available climate projections the Long-Term Adaptation Scenarios (LTAS) study (DEA, 2013), the expectation is that by 2040-2060 the Western Cape could experience 0.25m – 0.75m of eustatic rise and associated swash run up of roughly 3.0m – 3.5m above the mean sea level (no tidal influence). Sea-level rise lags temperature rises and is expected to accelerate towards the end of this century. The 2013 LTAS report recorded the associated loss of property and tourism to be between R211,5bn and R385.5bn for the entire country by 2100 (in 2010 prices).

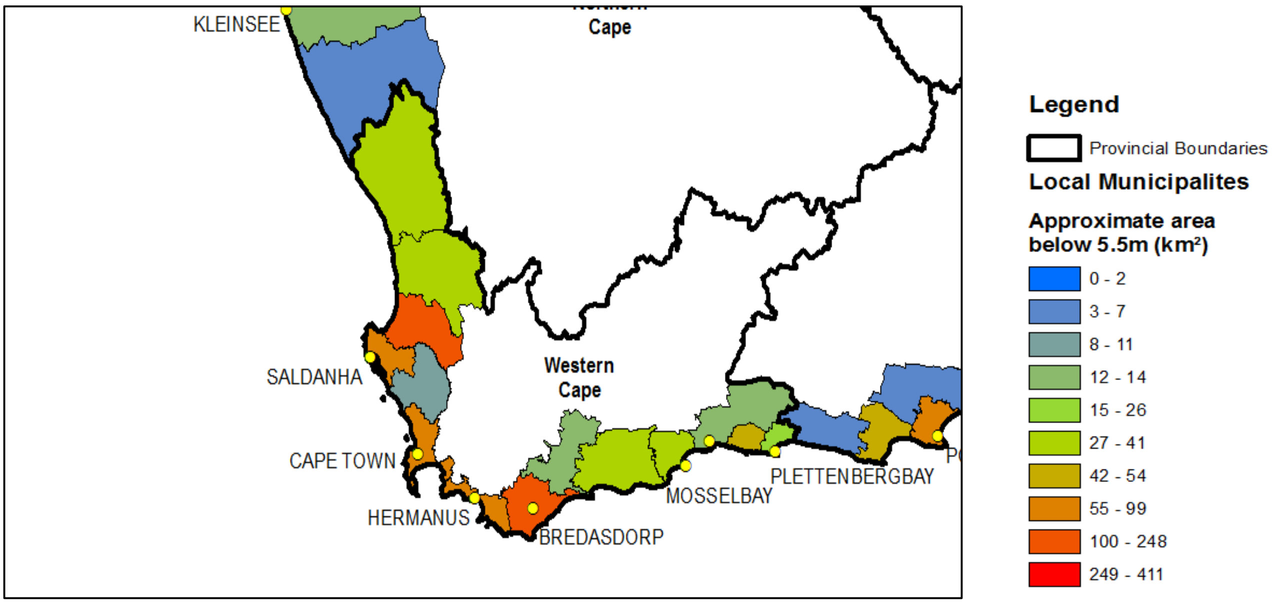

Figure 3: Extent of total area affected by sea-level rise in Western Cape's coastal municipalities (Source: DEA, 2013)

By 2040, the "low" and "high" scenarios in Table 1 can be reasonably anticipated as the result of climate change in the Western Cape, based on current information and expert opinion[10]. Notably, these changes are predicted at 2040 and will not be immediate. The scope and pace of change will ultimately affect how different sectors are affected, and how role-players within the commodity value chains respond to remain competitive.

Table 1: Projected 'low' and 'high' climate change impacts in the Western Cape for the 2040-2060 period

+1.5 °C	Δ Mean Temperature	+2.5 °C
No change	Δ Rainfall	-20%, longer dry spells
-10%	Δ Run-off	-30%, longer dry spells
No change	Δ Flood severity	Small increase
No change	Δ Southeast wind	Increase (Summer)
+0.25m	Eustatic sea-level rise	+0.75m
+3.0m	Storm surge	+3.5m

Low Climate Change Impact ⟷ High Climate Change Impact

While there is increasing scientific certainty about the direction and extent of climate change, predicting the timing and precise impact at the local scale is subject to innate uncertainty caused by different ranges of warming at the global sale, local topography and weather effects and the nature of social and policy responses to climate impacts. Recognising that anthropogenic warming will increase uncertainty is a key finding in itself – it is possible to manage for uncertainty and this ability will become increasingly valuable as the climate system is progressively perturbed and erratic.

This uncertainty is significant for economic modelling and is factored into this study by way of scenarios that adjust the extent of warming in the Western Cape and the institutional and societal capacity to cope with the multiple impacts of climate change through effective climate adaptation.

2.2.4 Defining future scenarios and associated assumptions

To model the economic impacts of climate change and climate resilient investment in the Western Cape, a series of future scenarios needed to be defined.

Given uncertainties about the severity and timing of the predicted changes in climate, and the anticipated variability in the severity of impacts arising from climate change across different parts of the Western Cape, a key variable used in developing the model scenarios

[10] As part of the study process, a comprehensive literature review was undertaken that informed the identification of likely high and low climate impact variables for the region. Meetings were then held with experts from CSAG, which resulted in minor refinements of the variables to reflect the most recent knowledge of the anticipated range of Western Cape specific climatic changes for the 2040 to 2060 period.

was the level of anticipated climate change impacts (i.e. high to low). By developing different scenarios that reflected either high or low levels of climate change impact, it was possible to evaluate 'best and worst case' economic futures as related to the amount of climate change that the Western Cape may ultimately experience.

The second key variable used in defining the scenarios was the level of adaptation to the impacts of climate change implemented in the Western Cape (i.e. also high to low). By developing different scenarios that reflected either high or low adaptation responses in the province, it was possible to determine how this variable would influence the provincial economy.

The four scenario's that were defined included:

1. **Boiling Frog** – Low climate change impact and low adaptation response
2. **Roaming Antelope** – Low climate change impact and high adaptation response
3. **Panicking Dinosaur** – High climate change impact and low adaptation response
4. **Fighting Lioness** – High climate change impact and high adaptation response

2.2.4.1 *Roaming Antelope: "Low climate change impact, high adaptation response"*

Changes in climatic conditions are not as severe as some models anticipated. The changes that have occurred have been well managed, securing the availability of food and water. Preparation for climate change has generated an opportunity cost, but the new capacity and focus has stimulated the green economy, which flourishes and creates new jobs. The cost of living and the cost of the insurance fall and new competitiveness is gained in climate resilient sectors. The property market has flourished, with the Western Cape remaining a destination of choice for international travellers and investors. Innovation in urban water efficiency continues, but is not particularly urgent. Agricultural water use has innovated due to greater competition and greater climate variability. There is good management of natural systems, such as watersheds and wetlands, to buffer climate variability.

The drought of 2015-2017 makes citizens more aware of resource scarcity and the need for efficient resource use. There is some political gamesmanship afoot regarding the reallocation of resources to ensure climate resilience, but overall there is a sense of confidence that all departments within the WCG, and other spheres of government in the province, have a handle on the situation and that they are justifiably cautious and watchful. This confidence has also been noticed country-wide and is reflected in a steady but consistent flow of people and investment to the province, contributing to its economic prowess and stability.

2.2.4.2 *Fighting Lioness "High climate change impact, high adaptation response"*

Environmental conditions deteriorate and become increasingly variable. The WCG has been warned and is prepared for the challenge. Due to strong leadership, innovative research and decisive and pro-active decisions, the WCG's new climate and green economy initiatives are effectively dealing with shortages and extremes.

The pre-emptive investment into vulnerable localities ensures a new inclusiveness, social stability and confidence in government. The result is that even though climate change has been more severe than was expected by median forecasts, public goods are well-managed and policies to protect people from extreme events gain international acclaim. Decisions to manage the increasingly scarce natural resources prudently and equitably are paying off. Social cohesion is strong, and all levels of society are participating and finding new economic opportunities for combatting the consequences of climate change. Examples include households generating power, water harvesting, and agriculture evolving to become a net carbon sink.

The supply of water, energy, and food is under pressure, but scarcity is managed, local markets are emerging, farmers are innovating, and urban gardens are flourishing. The clear message is that society understands that only through collective action can they, together, progress. The flow of communication regarding the impact of climate change has been effective and public awareness is high.

Agriculture faces dramatic changes in water availability and affordability, but demonstrates innovation and flexibility in food crops and water use technologies and efficiency.

Due to the WCG's foresight, the Western Cape has become a regional haven for both people (in-migration) and money (investment), and the recognised hub from which Africa's green economy was launched. Decisive shifts in education and training, led by industry and government, leads to the emergence of a technology revolution that opens the door to the changing economic environment and the rise of the 4th Industrial Revolution.

2.2.4.3 Boiling Frog: "Low climate change impact, low adaptation response"

The changing climate has not generated any urgency or enough of an appropriate behavioural response. Urgent, knee-jerk responses prevail over orderly planning and investment, without adequate structural shifts to meet climate and social changes. The historical perception that the Western Cape is a well-managed province creates a sense of false security and an expectation that the government will do what is needed when necessary, but the problem is too technical for politicians and too political for technocrats. Inadequate effort is made to position the Western Cape for climate change or to ensure that the gradually increasing indigent population is buffered from its most severe consequences. This results in higher demand for, and increasing total cost of, services. In the short term, fiscal transfers from rich to poor support service delivery roll-out, but this becomes untenable as the economy slows and the need increases. Inequality and social discontent rise. Growing informality undermines the impact of policy and governance and further raises the cost of formal service provision.

Over time, water *per capita* declines as the Western Cape becomes drier, demand grows with in-migration and supply becomes more variable. Water competition increases. Instead of confronting various developmental and structural issues proactively and collectively, it is each person for themselves. Unwittingly, slowly but surely, the Western Cape crosses a tipping point and is faced with an increasingly polarised society; while the rich retreat to their gated villages, the poor eke out a living using nature's degraded and declining provisions in poorly serviced informal settlements.

Given the policy ambivalence, lack of vision and action, social unrest is common-place leading to a slow but progressive decline in investment and the ongoing haemorrhaging of economic opportunities.

Little new knowledge development takes place and innovation remains a scarce luxury. The cost of living is high with frequent natural disasters, including fire, flooding and water shortages. This takes investment away from regular maintenance and so service breakdowns are regular. Insurance is only affordable for the wealthy. Businesses vote with their feet and relocate, leaving higher unemployment behind.

2.2.4.4 <u>Panicking Dinosaur: "High climate change impact, low adaptation response"</u>

Yet another flood, yet another fight. All the signs were there but the will to act was undermined by easy rather than important and unpopular, decisions. Intense changes in the climate and climate-related events occur, but the social safety net is in tatters. Most of the Western Cape is uninsurable.

The extreme conditions lead to knee-jerk reactions by decision-makers, residents and investors alike, but it is all too little too late. Those that can afford it, isolate themselves in self-serving enclaves serviced by boreholes and household-scale electricity solutions, but they withhold their investments in the future. Some leave for greener pastures, taking their money and businesses with them. Those that cannot afford to leave become increasingly opportunistic in trying to safe-guard their livelihoods. In the process both rich and poor undermine governance and societal interests such as functional natural environments and a stable economy. In the governance vacuum, illicit business interests and gang culture gain an even stronger influence.

Social fragmentation and bitter polarisation is at an all-time high with the affluent building bigger walls to isolate themselves from the poverty and deprivation that is growing daily. Conflict becomes endemic, with competition for declining resources, and agriculture is disrupted on a large scale. The weak are increasingly becoming more vulnerable as the property rates base shrinks and service revenues decline, leading to a fiscal cliff in the public sector and the likelihood of rampant food price increases, the closure of business and the termination of service delivery, all in the wake of public systems collapse. Those businesses and households that can, escape the water and energy crisis by moving away from the province or privatising their supply, contributing to the fiscal crisis in the process. This leads to accelerated economic decline and higher inequality, and an inadequate supply of life-supporting ecosystem goods and services and resources such as water, energy and food.

Figure 4: Summary of the four Western Cape future climate change impact / adaptation scenarios

The expected changes in investment in the five priority economic sectors (i.e. agriculture, water, energy, transport and construction) were identified for each of the future scenarios to the year 2040 using available data and expert opinion.

2.2.5 Running the model using different assumptions

The expected changes in investment in each of the five priority sectors was modelled for the four scenarios. The CGE model was run three times over, with each respective run evaluating the impact that climate change and climate adaptation investment in the Western Cape would have on the provincial economy:

Model Run 1 – Assumes other provincial economies are not negatively impacted by climate change (i.e. singling out the Western Cape economic impacts from regional economic change);

Model Run 2 – Assumes other provincial economies are impacted negatively by climate change (i.e. highlighting the role of other provincial economies in the health of the Western Cape economy);

Model Run 3 – Assumes all provincial economies proactively invest in climate change adaptation (i.e. highlighting how a national-scale response to climate change would impact the Western Cape economy).

2.2.6 Analysis of the results

The model results were collated and analysed and are presented in the following section.

2.3 Results

2.3.1 Impacts on GDP and Employment

Through modelling the four scenarios across three different runs (note that Run 3 only modelled two of the scenarios), ten different simulations of the potential economic impact of climate change and climate resilient investment on the Western Cape have been created – each with a separate set of assumptions underpinning it.

Figure 5 shows that from T0 (2016) to T1 (2040), the Western Cape's Provincial GDP may either contract by as much as 17,8% (Panicking Dinosaur scenario Run1 – i.e. assuming other provincial economies are not negatively impacted by climate change), or increase by as much as 15,3% (Fighting Lioness Run 2 – i.e. assuming other provincial economies are negatively impacted by climate change). From a GDP perspective, the worst-case situation is therefore one in which the WCG does less than other provinces to adapt to climate change. The best-case situation is one in which the WCG invests effectively and early in climate adaptation, and is a national leader in doing so.

Effective investment in enhancing climate resilience could boost the province's GDP by more than 15% by 2040, particularly where the Western Cape is a national climate adaptation leader.

Failure to invest adequately in adapting to climate change could contract the Western Cape's GDP by more than 17% by 2040, particularly if other provinces are more effective at adapting to climate change.

The difference between the worst case (-17,8% GDP contraction) and best case (+15,3% GDP growth) scenarios represents a 33% difference in GDP by 2040. This reflects the significant scale of economic risk and / or opportunity the province is exposed to with climate change.

By investing in improved climate resilience, the Western Cape economy could be 33% better-off in 2040 than if the province does not adapt effectively to the impacts of climate change.

The model findings suggest that the economic impact of climate change is, in part, the result of a competitive process between regions. If the Western Cape adapts proactivey and better than other provinces, it will attract inevstment and people (that exert downward pressure on labour costs), and so gives the province an economic advantage.

That climate change adaptation could be construed as a competitive process between regions is an important and interesting finding. In the long-run it might be expected that the negative contagion effects from other provinces that suffer economic decline from climate change might eventually catch up with the Western Cape economy through less trade. This is particulatly the case where structural rigidity in the labour market prevents in-migration from reducing labour costs.

Figure 5 also shows a comparison between the changes in Western Cape Provincial GDP and National GDP for the ten model simulations. It is evident from the graph that where climate change serves as a catalyst for proactive investment in climate adaptation (i.e. the Roaming Antelope and Fighting Lioness scenarios), the net economic impact of climate change could be positive in the province. The resulting acceleration of the Western Cape's GDP growth could exceed National GDP growth in this instance.

However, an apathetic response to climate change involving inadequate investment in adaptation (i.e. the Panicking Dinosaur and Boiling Frog scenarios) would lead to a contraction in both Western Cape and National GDP. The Western Cape's GDP would contract more significantly than National GDP where the Western Cape is less effective in adapting to the impacts of climate change than elsewhere (i.e. Run 1 of the Panicking Dinosaur and Boiling Frog scenarios in which other provincial GDPs are assumed not to be negatively impacted by climate change).

The effectiveness of the Western Cape Government's climate adaptation policies, along with the reactions of other provinces, could significantly affect the extent of Provincial GDP growth or contraction by 2040.

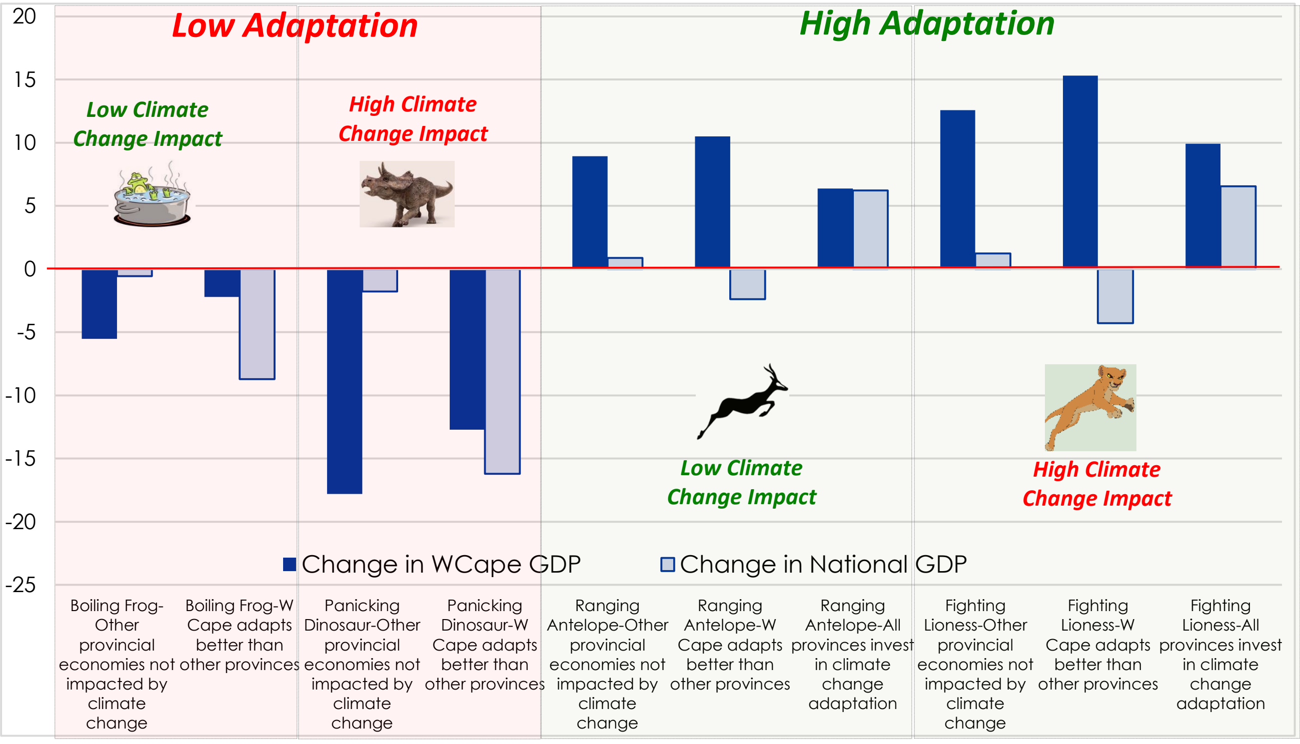

Figure 5: Comparison between the percentage change in Western Cape GDP and National GDP in the ten model simulations

The sizes of the adaptation interventions also matter. GDP grows more with a greater increase in capital stocks, while investment in labour and changes in the economy of other provinces also influence the levels of change in GDP. If the Western Cape adapts better than other provinces, increases in capital stocks are likely to have a greater positive impact on Western Cape GDP and employment levels.

Since total production is a function of capital, labour and technology, positive shocks to capital stocks would be expected to increase production and therefore increase GDP. Labour is the second major factor influencing production. In the model, it is assumed that national employment levels remain constant in the long run[11]. However, labour could migrate between provinces, and hence the model results reflect possible changes in employment levels in the Western Cape across the 10 model simulations.

Figure 6 demonstrates that it is not only important to be able to mobilise an investment response to climate change, but that the size of the investment response matters. Comparing the high adaptation and low adaptation scenarios across each model run, we see that GDP always does better with a greater positive change (or less of a decline) in capital stocks. For example, GDP in Run 1 of the Fighting Lioness scenario is better than Roaming Antelope Run 1, and better in Boiling Fog Run 1 than Panicking Dinosaur Run 1. The only difference in each case is the size of change in capital stocks.

The greater the investment in climate resilience, the greater the benefits to the Western Cape economy.

In the best-case situation, high levels of investment in climate adaptation increases capital stocks in the Western Cape by 18%. This occurs when climate change impacts are severe, but are met with a significant investment in an effective adaptation response. Climate change could therefore be a catalyst for accelerated economic growth in the Western Cape, with growth of 10% and 15% above baseline levels possible by 2040. With this level of economic growth, employment levels may increase by 12.4% above baseline by 2040. However, if all provinces adapt to climate change, or if other provinces adapt better than the Western Cape, then GDP and employment growth in the Western Cape are more muted.

If the Western Cape is less impacted by climate change, or adapts better than other provinces, the required investment in new capital is less and the capital stock expands by 13% above baseline by 2040. This investment would have a proportionately greater effect on growth as climate losses are lower, and GDP could grow by 6,4%-10,5% above baseline.

In the worst-case situation, the Western Cape does not invest adequately in climate change adaptation and other provinces do, causing capital stocks in the Western Cape to contract by as much as 23.9% by 2040. Employment levels could drop by 10.4%, as workers migrate to other provinces where the economy is more buoyant.

Employment levels in the Western Cape could increase by as much as 12.4% by 2040, if the province leads in adapting to climate change.

However, employment levels in the Western Cape could decline by as much as 10.3% by 2040, if the province fails to invest adequately in adapting to climate change.

Figure 6 shows that Run 3 of the Roaming Antelope and Fighting Lioness scenarios - in which

[11] The official unemployment rate in South Africa has remained more or less constant for more than two decades. In the model, it is therefore assumed that shocks applied to capital stocks would not change that trend.

all provinces adapt to climate change in accordance with their assumed ability to do so - demonstrates an anomaly in which GDP grows between 5% and 10%, yet employment stays stable or increases only marginally. This is because the model simulations present long run[12] outcomes.

Figure 7 demonstrates that if the Western Cape economy is less negatively impacted by climate change than elsewhere, in-migration would depress wages and lead to increased employment levels in the Western Cape, with employment in other provinces declining. This model finding assumes wage flexibility and that people moving to the Western Cape can be effectively provided with services and work (which may not be the case in reality). In-migration caused by climate change impacts in other regions, however, could be associated with potential economic benefits for the host region, as economically active people lend their contributions to the host economy.

Anticipating and meeting new skills and training needs in an expanding climate resilient economy in the Western Cape will be critical.

A more inclusive climate resilient economy will be achieved through equipping the provincial workforce with the right skills to participate in it.

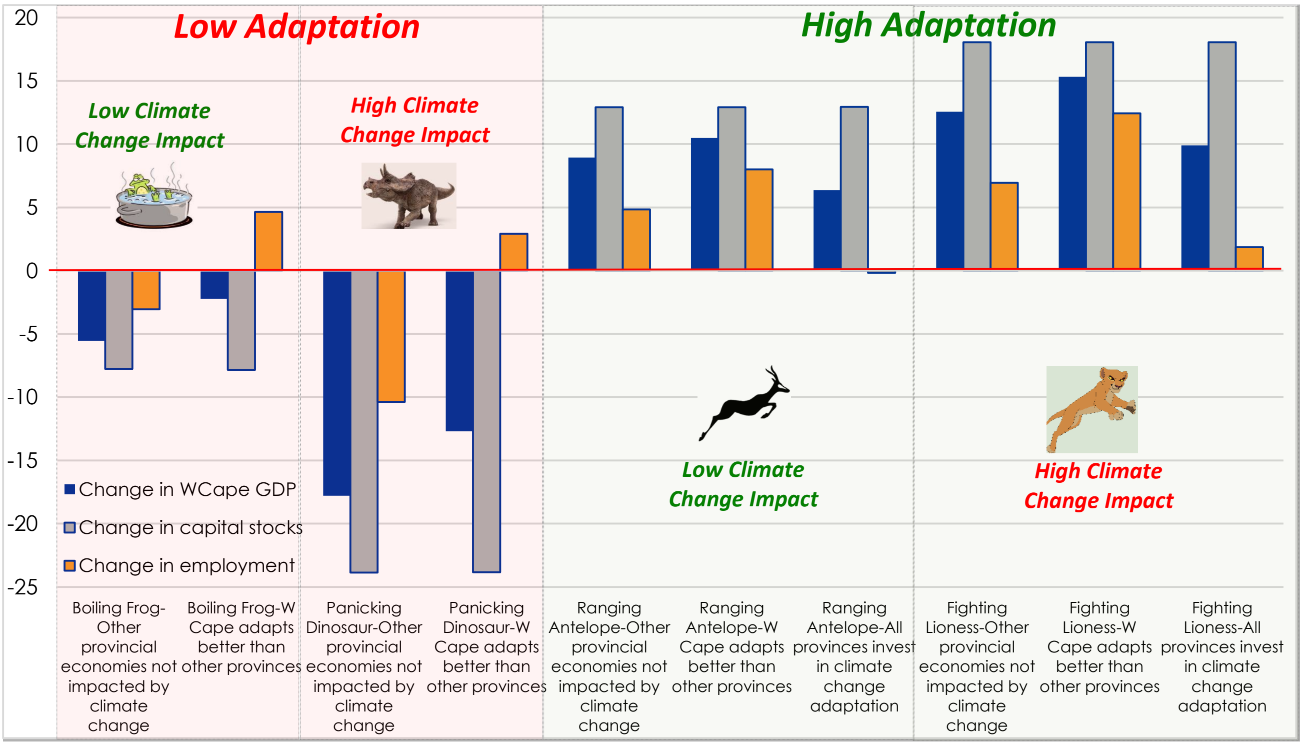

Figure 6: Percentage change in capital stocks, GDP and employment levels in the Western Cape province in the 10 model simulations

[12] All model simulations present the long run (to 2040) outcome. In agriculture, for example, it would be expected that by 2040, the active work force would be much smaller than the baseline (2016), but the sector produces more with increased capital and better technologies.

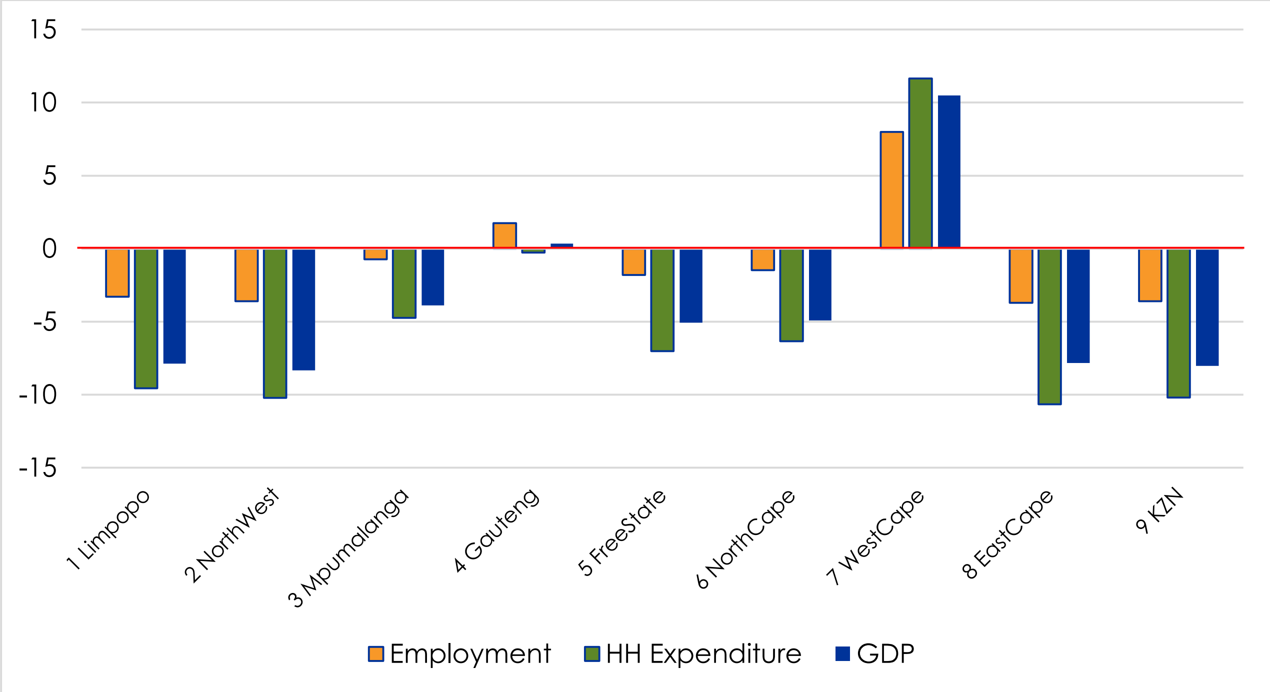

Figure 7: Comparison between percentage change in GDP, employment and household (HH) expenditure per province under Run 2 of the Roaming Antelope scenario

2.3.2 Price Changes

The model operates in terms of relative percentage changes and not in changes to absolute values. Price changes are measured in terms of Consumer Price Inflation (CPI), but CPI can be defined for a particular province relative to the rest of the country.

Prices directly influence household consumption levels. A surprising result from the climate change modelling was that household consumption emerged as the most significant variable determining economic growth or contraction. In South Africa, where more than half of all people live in poverty, the climate change response policies adopted by government must therefore take careful consideration of the associated price impacts on households.

Climate resilient investment in different sectors will result in price changes, affecting cost of living, economic competitiveness, and social equality.

Figure 8 shows that CPI in the Western Cape decreases relative to National CPI in several of the model simulations. The greatest decreases in CPI are achieved in the high adaptation scenarios (i.e. Fighting Lioness and Roaming Antelope), in which the WCG is assumed to respond proactively to climate change by increasing capital stocks above depreciation levels. In these cases, the outcome is a decrease in consumer prices relative to the rest of South Africa, which is achieved through new people and new investment exerting downward pressure on wages and prices respectively, making the province more competitive.

Similarly, we see that in Run 2 of the Roaming Antelope and Fighting Lioness scenarios (i.e. where the Western Cape adapts more effectively than other provinces), the Western Cape CPI decreases relative to National CPI. This is because capital stocks in other provinces are contracting while those in the Western Cape are increasing, and so the Western Cape becomes increasingly competitive.

Interesting and somewhat unexpected results appear under Run 2 of the Panicking Dinosaur and Boiling Frog scenarios. In these examples, the Western Cape experiences a decline in capital stocks due to inadequate investment in climate adaptation, and should therefore become less competitive. However, the provincial CPIs decrease relative to the national average. The reason in both cases is the assumption that capital stocks in Gauteng would decrease more than in the Western Cape. Gauteng is a strong economy and their influence dominates in this case: their prices increase relative to the rest of South Africa, which makes the Western Cape relatively better off.

The price changes seen in Run 3 (i.e. where all provinces adapt to climate change) are not very different from the rest of South Africa, because the strong climate adaptation policies adopted by Gauteng in this example would be such that the Western Cape would not observe any competitive advantage or disadvantage.

Under Run 1 of the Panicking Dinosaur and Boiling Frog scenarios (i.e. where other provinces are assumed not to be negatively impacted by climate change), Western Cape prices increase relative to the rest of South Africa. In this example, other provinces keep their capital stocks intact (or grow them on the baseline) while the Western Cape's capital stocks are declining. As the Western Cape loses its competitive advantage, relative prices in the province increase in comparison to the rest of the country.

By becoming a national leader in climate resilience, the Western Cape can increase its competitive advantage and reduce its prices.

The best-case situation from a CPI perspective is therefore one in which the Western Cape adapts better to the impacts of climate change than other provinces, thereby attracting labour and investment, increasing its competitive advantage and reducing its prices. Conversely, the worst-case situation is one in which the Western Cape adapts less effectively than other provinces, and so erodes its capital stocks, loses its competitive advantage and experiences increasing prices because of labour and capital scarcity.

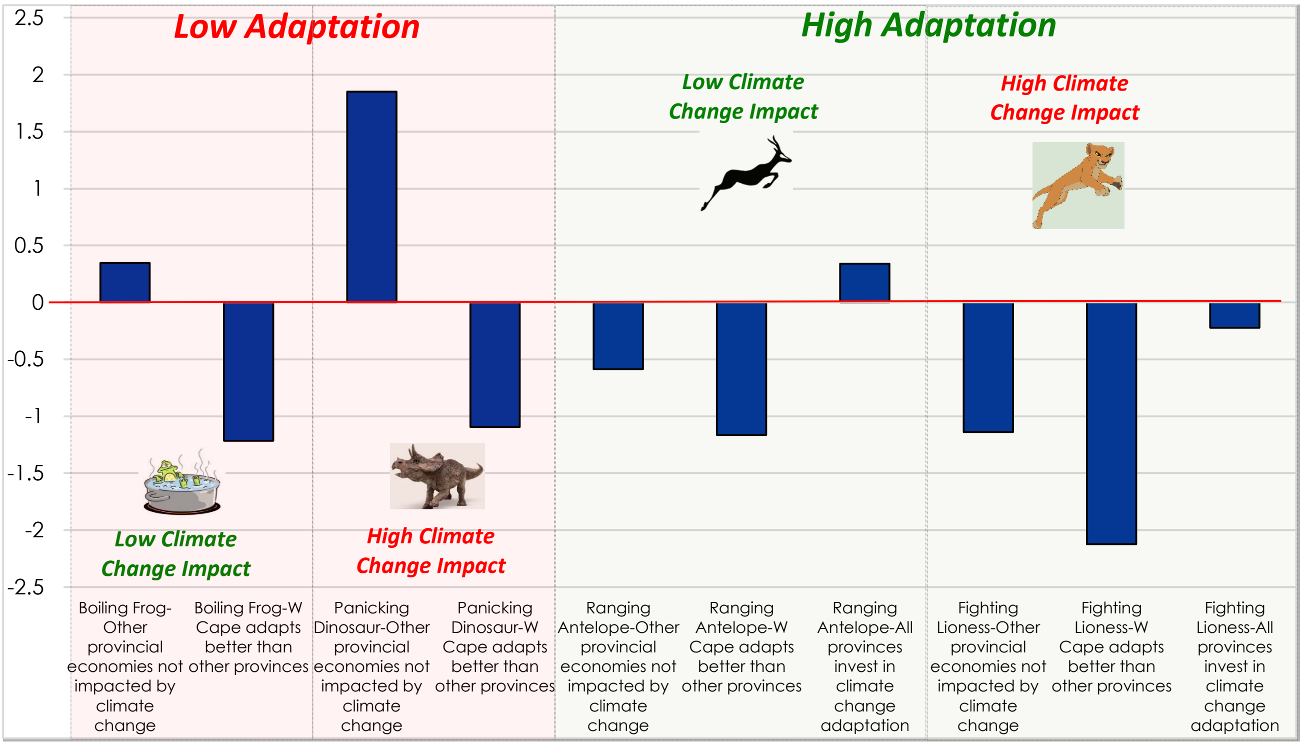

Figure 8: Percentage change in Western Cape CPI relative to National CPI (assumed to be 0%) across the ten model simulations

2.3.3 Household Expenditure on Consumer Goods

In addition to affecting export volumes, domestic consumer prices have a direct impact on levels of household consumption. The modelling showed that changes in household consumption plays the major role in driving GDP growth or decline at a provincial level. Figure 9 uses the low climate change impact scenarios (i.e. Boiling Frog and Roaming Antelope) to show that changes in household expenditure contributes the major portion of total GDP growth or contraction.

Proactive investment in climate adaptation in the Western Cape could benefit households by making the cost of living lower. This is potentially a major driver of GDP growth and increased quality of life in the province.

Conversely, failure to invest adequately in adapting to climate change could lead to increased household cost of living in the Western Cape, with declining quality of life and a contracting GDP.

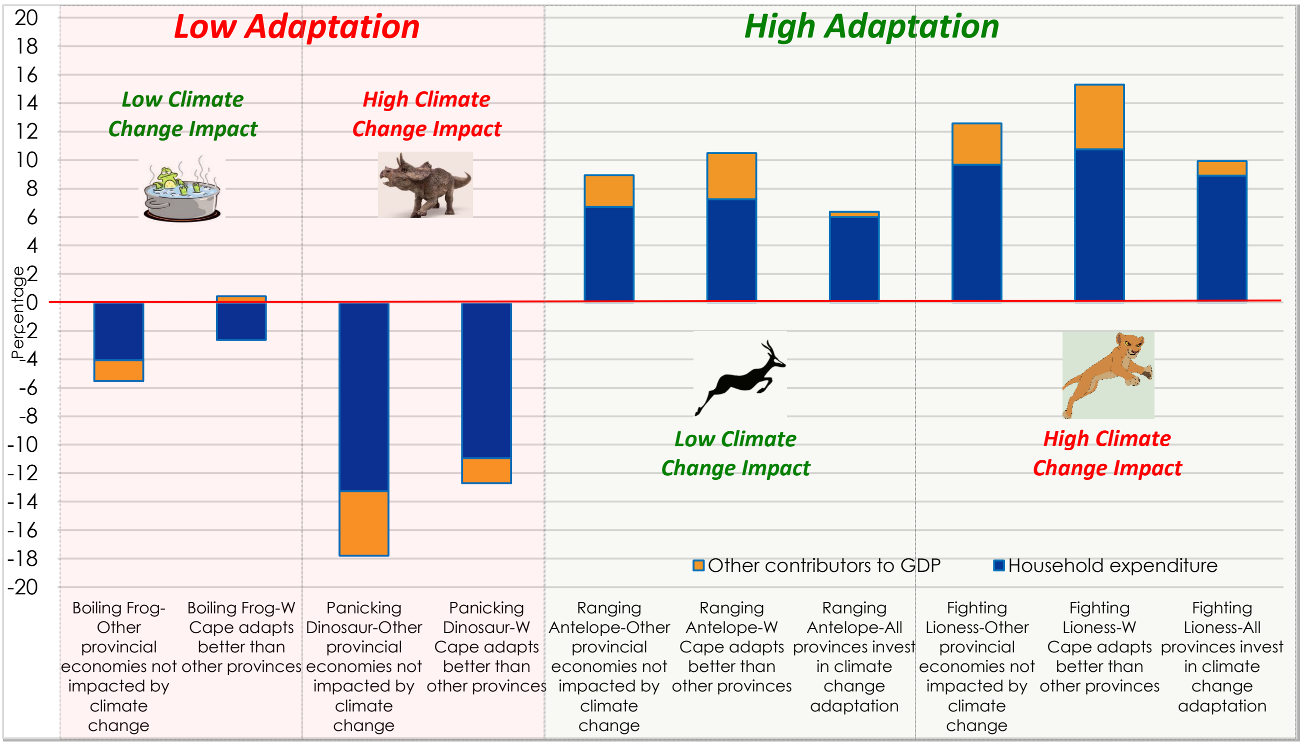

Figure 9: Contribution of household expenditure to total change in Western Cape GDP ('other contributors' includes changes in provincial imports and exports, government expenditure, investment expenditure and stocks)

Government's choice of which sectors to prioritise for climate adaptation investment is crucially important for households. Figure 10 shows the respective contributions of the 27 commodities in the CGE model to the total change in national household expenditure (in Run 1 of the four scenarios). The most important sectors for household consumption are:

- Real estate services (which includes with the renting and buying of houses, and paying instalments on property bonds / loans) represent the single largest expense item in most household consumption baskets.
- Food and beverages are important commodities for households, and stimulating agriculture and water services has a direct effect on the food sector, which is the main buyer of agricultural goods;
- The transport services and transport equipment manufacturing industries emerge as important items in the consumer basket;
- Households are furthermore very reliant on energy as a commodity in their consumption basket, in the form of petrochemicals manufacture and electricity supply.

The agriculture, water, electricity, transport and real estate services sectors affect household expenditure significantly, and should be prioritised for climate resilient investment.

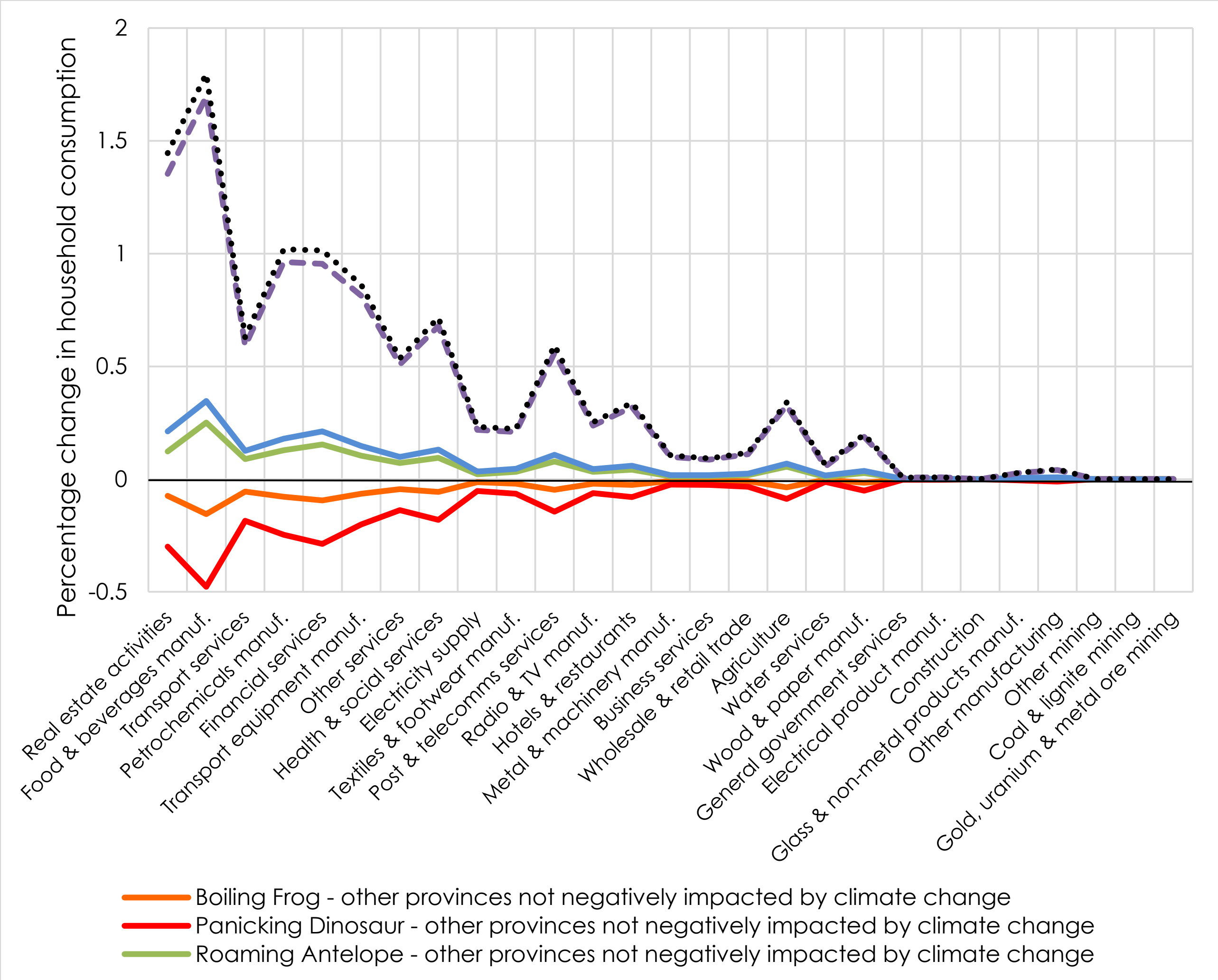

Figure 10: Percentage change in household consumption per industry sector in Runs 1 and 3 of the scenarios

2.3.4 Local and International Trade

Imports and exports play a key role in South Africa's national economy, forming an integral part of national GDP. Similarly, all provinces within the country are highly dependent on trade with other provinces (i.e. intra-regional trade), as well as with the rest of the world.

GDP and trade – whether intra-regional or international – are strongly linked, with both imports and exports tending to increase when the GDP is strong. This is because strong GDP implies high levels of productivity, resulting in increased import demand for goods and services required as inputs for production, and high levels of output which support increased levels of exports.

Figure 11 shows that there is a strong relationship between the size of total foreign trade (the sum of imports and exports) and the size of GDP (i.e. not growth rates). The two scenarios associated with proactive investment in climate adaptation (i.e. Roaming Antelope and Fighting Lioness, on the right of the graph) result in stronger provincial GDP, with increased international trade making a key contribution. Whereas the low adaptation investment scenarios (i.e. Panicking Dinosaur and Boiling Frog, on the left of the graph) result in GDP contraction and a reduction in international trade.

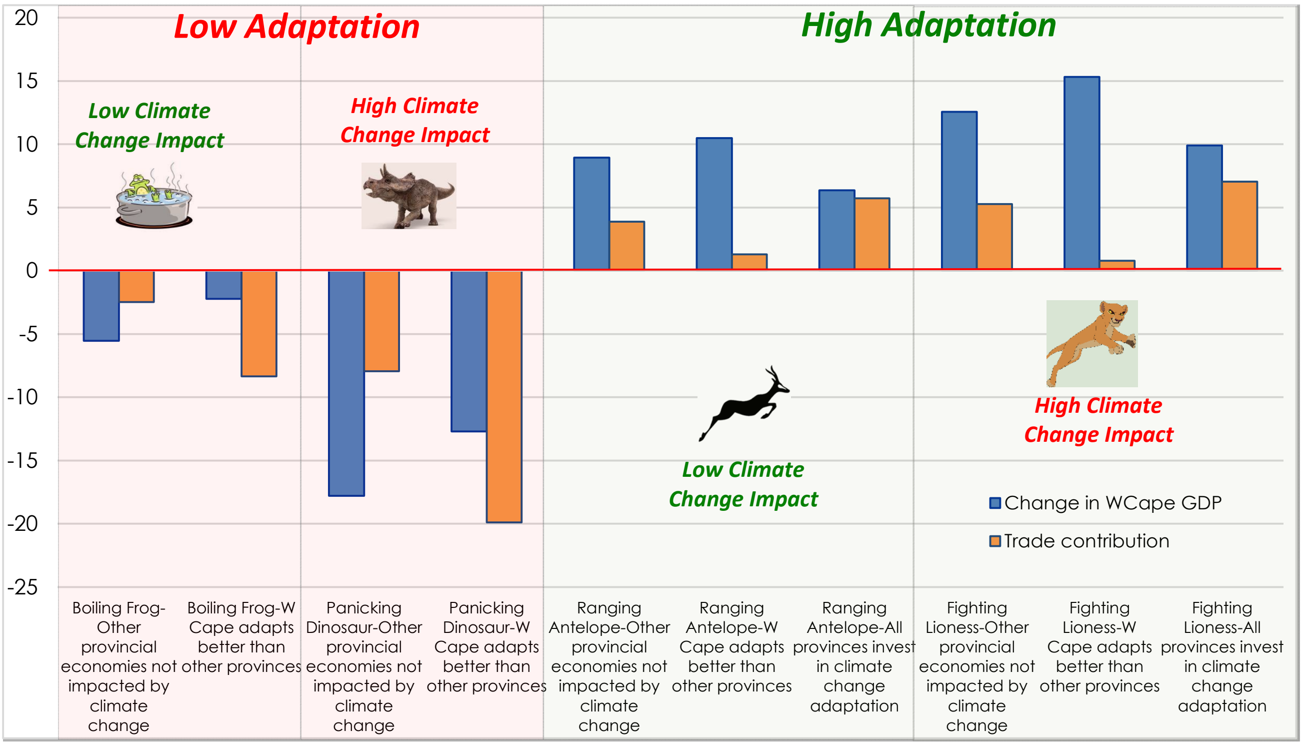

Figure 11: Relationship between change in Western Cape GDP and change in total foreign trade (total international imports and exports)

While imports and GDP are related, domestic consumer prices of commodities are also strongly, yet inversely, related to the export volumes of the same commodities. If South African commodity prices increase, foreign buyers must pay more for South African goods, and so tend to buy less. When domestic consumer prices decrease, South Africa becomes more competitive in international export markets and export trade increases.

In the national context, provinces require other regions of the country to have productive economies that drive demand for intra-regional trade.

Figure 12 shows how changes in the rest of South Africa's economic status can affect the Western Cape province's ability to engage in regional trade. In Run 2 of the Roaming Antelope and Fighting Lioness scenarios, other provinces are declining economically due to inadequate climate adaptation investment, impacting negatively on the Western Cape's regional exports. In this example, the Western Cape still benefits from increasing competitiveness and grows its international exports and imports. By contrast, in Run 3 of the Roaming Antelope and Fighting Lioness scenarios, where all provinces are proactively investing in climate adaptation, the national economy is buoyant and the Western Cape's regional exports and imports increase significantly. However, its international exports decline as other provinces compete with the Western Cape for international trade opportunities.

A key driver of these economic losses or gains is the net impact of climate change and adaptation investment on prices and costs, and the associated impact on competitiveness. The implication is important: climate change will reconfigure economic competitiveness regionally and globally; and effective investment in climate adaptation could serve as a critical catalyst for the increased economic competitiveness of the Western Cape.

Regional exports from the Western Cape could increase by 6.4% by 2040 with enhanced climate resilience.

Even if the WCG invests effectively in climate change adaptation, but other provinces fail to adapt, growth of the Western Cape economy will be constrained in the medium to long-term by reduced intra-regional and international trade.

The Western Cape needs other provinces also to adapt to climate change for there to be strong intra-regional and international trade in the medium to long term.

The results of the two Boiling Frog scenario runs in Figure 12 show that if the WCG does not invest adequately in adapting to the impacts of climate change, intra-regional and international imports and exports could all decline significantly. If other provinces also don't adapt effectively (i.e. Run 2 of the Boiling Frog and Panicking Dinosaur scenarios – where other provincial economies are assumed to be negatively impacted by climate change), these declines can be expected to be much greater.

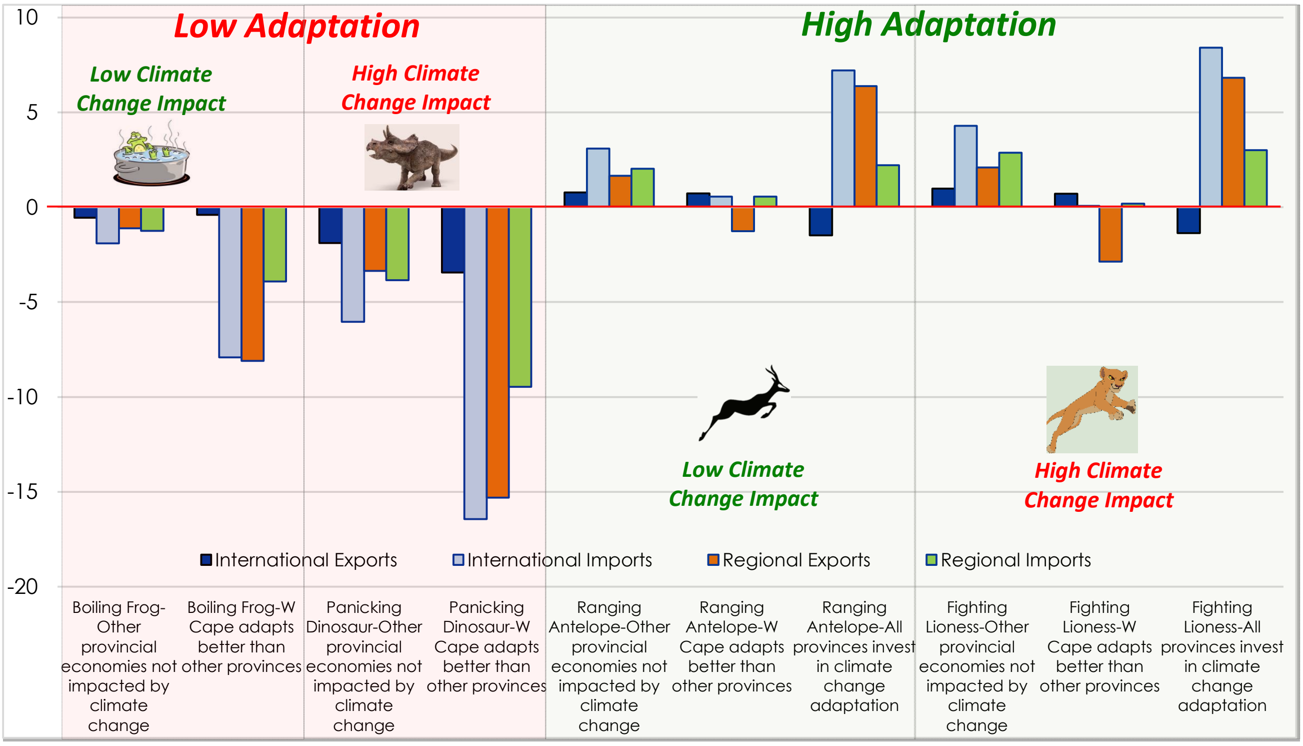

Figure 12: Change in imports and exports in the Western Cape under the four scenarios

Figure 13 shows how national agricultural output would change, as modelled under Run 2 of the Roaming Antelope scenario, in which it is assumed that the WCG is more proactive in adapting to climate change than other provinces. The results show that the declining agricultural productivity in most of the other provinces is significant enough to cancel out any growth in this sector in the Western Cape, and national agricultural output decreases overall.

While agricultural output in the Western Cape increases by 2.4%, and in Gauteng by 0.06%, the combined reduction in agricultural output in all other provinces is close to 4.8%. This results in a net reduction in agricultural output nationally of 2.32%.

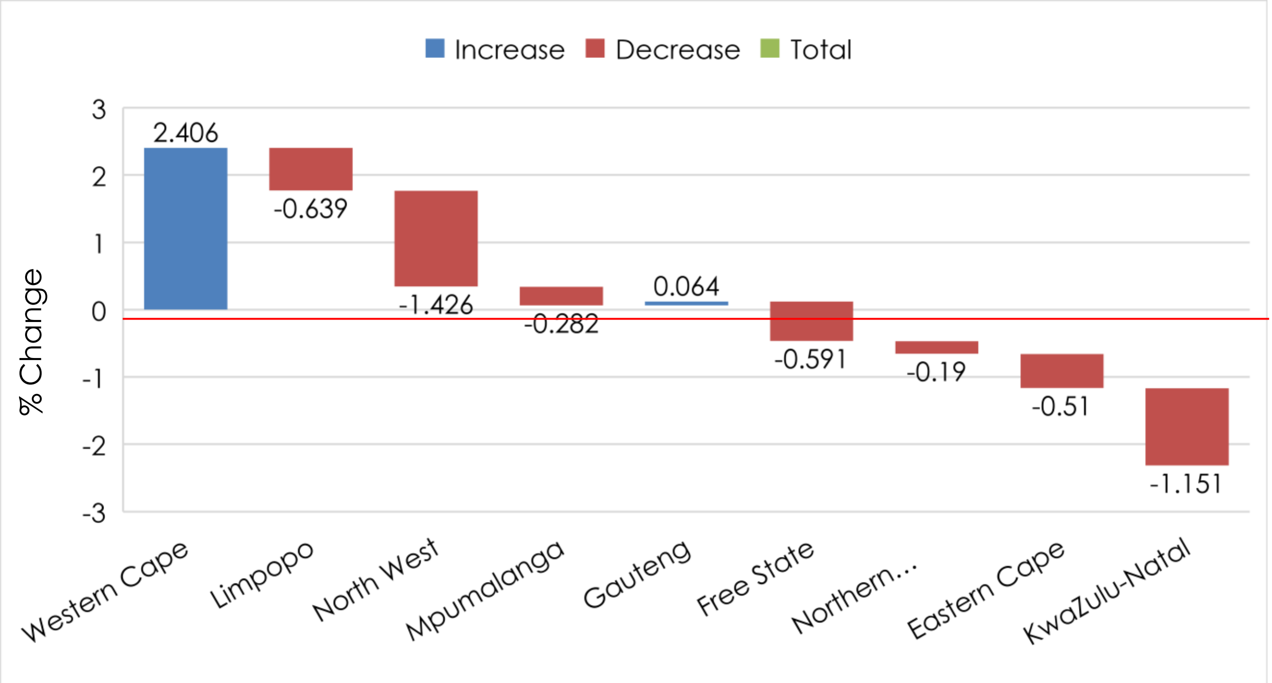

Figure 13: Percentage change in national agricultural output by 2040 disaggregated per province, in the Roaming Antelope scenario, Run 2

2.3.5 Industry Winners and Losers

Figure 14 captures an important finding from the model, namely that there may be highly differentiated sectoral impacts within the overall economic impact of climate change and climate resilient investment on the Western Cape economy. The figure displays the impacts on different economic sectors that could occur where all provinces adapt effectively to climate change (i.e. Fighting Lioness, Run 3).

Three factors appear to influence which sectors are most and least affected:

- The capital to labour ratio in each sector, and how investment in climate adaptation affects demand for capital in each sector.
- The impact of shifts in demand created by climate change. Where export demand increases, due to a change in the exchange rate or growth of a particular sector for example, the export oriented sectors benefit.
- Changes in price, driven by supply and demand changes, and the influence of price changes on a sector's competitiveness.

The six most capital-intensive industries in South Africa are Real Estate Services, Other Mining, Agriculture, Other Manufacturing, Water Services and Electricity Supply - most of which are situated on the left of the figure, indicating a relatively high positive change under this scenario and model run.

Surprisingly, Agriculture and Other Mining, both lie towards the right of the graph amongst the sectors that are most adversely affected by climate change. The reason for this is that both industries use land as an input in the production process. As the amount of land in South Africa and each province is fixed, the model assumes that an expansion of economic activity (as assumed under Run 3 of the Fighting Lioness scenario) drives the price of land up. This influences the profits of land-dependent industries, and hence affects their levels of production.

The key inference from the model result is that climate change will generate sectoral winners and losers. The results suggest that important Western Cape sectors such as construction and real estate services might benefit significantly from investment in climate adaptation, whilst the most adversely affected mining sectors are not found in the Western Cape. At the same time, the restaurant and hotel industry, and the textile industry, both of which are important to the Western Cape economy, appear to suffer due to higher prices caused by climate change and resulting loss of competitiveness. Sectoral impacts are notoriously difficult to predict, but policy makers need to understand such differential impacts before crafting climate change policy responses.

Climate change and climate resilient investment will not affect all sectors equally. Policy makers must decide whether to protect the most exposed sectors or invest in the sectors that stand to benefit from climate change.

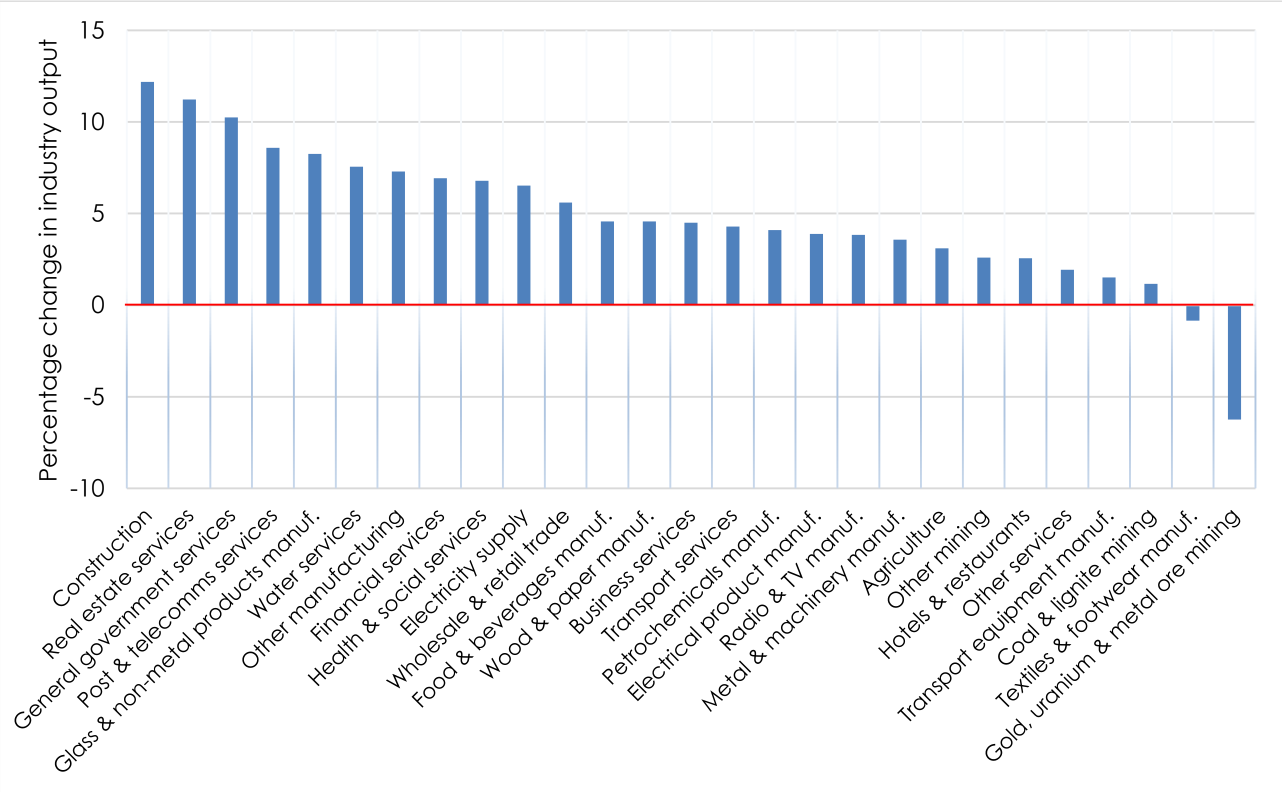

Figure 14: Percentage change in industry output under Run 3 of the Fighting Lioness scenario

2.3.6 Global and Local Carbon Pricing Implications

2.3.6.1 Carbon Pricing Instruments and Context

Carbon pricing aims to charge GHG emitters for the climate change damage they cause, thereby removing the perverse subsidy they receive when they are not held responsible for the 'externality cost' of their emissions. By making polluters pay for their damage, a carbon price alters the relative price of goods and services based on their carbon intensity. Price changes send the economy a signal that is intended to shift investment and consumption behaviour in favour of less carbon-intensive modes of economic activity.

The usual assumption is that a carbon tax represents a flexible and cost-effective climate mitigation instrument. Agreeing on a carbon price and charging it to emitters is not, however, easy. Options include a domestic tax on emissions or input resources, a border tax adjustment on imports or exports, or issuing an emissions quota to domestic industries above which emissions are 'fined'. High transaction costs, information imperfections and powerful vested interests frequently undermine the smooth and efficient influence of a carbon price on economic decisions (Colenbrander *et al.* 2017). However, countries such as Sweden and Costa Rica, and certain provinces in China and Canada, have been applying carbon pricing measures for some time and all of them have reaped economic benefits.

In May 2017, the "High-Level Commission on Carbon Prices[13]" released a report chaired by Joseph Stiglitz and Nicholas Stern. The Commission brought together thirteen leading economists from nine developing and developed countries to identify the range of carbon prices that, together with other supportive policies, would deliver on the aims of the Paris Agreement.

Stiglitz announced the report by stating:

"*The world's transition to a low-carbon and climate-resilient economy is the story of growth for this century….. We're already seeing the potential that this transformation represents in terms of more innovation, greater resilience, more liveable cities, improved air quality and better health. Our report builds on the growing understanding of the opportunities for carbon pricing, together with other policies, to drive the sustainable growth and poverty reduction which can deliver on the Paris Agreement and the Sustainable Development Goals.*"

The Commission concluded that a $40-$80 carbon price range in 2020, rising to $50-$100 by 2030, is consistent with the core Paris Agreement objective of keeping temperature rise to below 2°C, but recognised that carbon pricing needed to be tailored to in-country conditions.

2.3.6.2 Summary of the Proposed National Carbon Tax

The South African National Government, through the National Treasury in close collaboration with the Department of Environmental Affairs, is considering the implementation of a carbon tax (National Treasury, 2015). The key design features of the proposed tax include the following:

---

[13] During the 22nd Conference of the Parties (COP) of the UNFCCC held in Marrakech, Morocco, in 2016, at the invitation of the Co-Chairs of the Carbon Pricing Leadership Coalition (CPLC) High-Level Assembly, Ségolène Royal and Feike Sijbesma, Joseph Stiglitz, Nobel Laureate in Economics, and Lord Nicholas Stern, accepted to chair a new High-Level Commission on Carbon Prices comprising economists, and climate change and energy specialists from all over the world, to help spur successful implementation of the Paris Agreement.

1. The tax is effectively a fossil-fuel input tax levied on Scope 1 emissions, that is, emissions that result from fuel combustion, gasification, and non-energy industrial processes.

2. The tax is levied at R120/tCO_2-eq. The date of implementation is still under negotiation and has been postponed several times.

3. Every sector is provided with a basic exemption of either 60%, 70% or 100% of their emissions. Specific sectors not qualifying for the 100% exemption may qualify for further exemptions such as a trade allowance, a fugitive emission allowance, a carbon budget allowance, an offset allowance, or a so-called Z-factor allowance[14].

4. While not stated explicitly in the Draft Carbon Tax Bill (2015), it is anticipated based on earlier communications (National Treasury, 2013) that the revenue from the proposed tax will be recycled[15] *via* the national fiscus. In keeping with the National Treasury's strategy of retaining fiscal flexibility, the carbon tax policy paper does not make specific commitments about how the revenue will be recycled, although it lists several recycling and tax-shifting options. It is, however, the intention to use the revenue generated to support the structural transition towards a low-carbon economy, to protect poor households from the impact of energy price increases, and to stimulate the green economy.

From the above it should be clear that this is a complex tax whose economy-wide impact will be determined mainly by:

1. The sector and the applicable exemption threshold and its change over time,
2. The marginal tax rate and its change over time, and
3. The tax recycling scheme that is implemented.

2.3.6.3 National Carbon Tax Impacts on the National Economy

In 2015, the University of Pretoria Department of Economics and Futureworks used a dynamic CGE model to estimate the plausible impacts of the proposed carbon tax on the South African economy (note that the modelling was based on the National Treasury 2013 Carbon Tax Policy Paper) (see Van Heerden *et al.* 2016). While some of the tax design features have been amended in the 2015 Draft Carbon Tax Bill, the basic characteristics and tax exemption thresholds are the same. The main conclusions from this research were:

1. The exemption regime, and the speed at which it is applied, are both significant considerations. Under a scenario of no revenue recycling it was found that the proposed set of exemptions could reduce emissions by 38.3% relative to the baseline (i.e. no

[14] The Z-factor allowance is a sector specific performance allowance that allows firms that have implemented additional measures to reduce the greenhouse gas emissions to reduce their tax exposure.

[15] Tax recycling refers to the re-investment of the tax revenue by the National Treasury for a specific purpose in the national fiscus. Under a no tax recycling option, the tax revenue is added to the general national income (and other) tax income, reducing the government deficit, but is not used or allocated to specific purposes.

carbon tax) by 2035. Gradually removing all the exemptions could reduce emissions by 50.1%. In this case, should the tax revenue be recycled fully through, for example, a reduction in VAT, then the reduction in emissions were estimated to be 40.7%.

2. All taxes do reduce GDP, and so will a carbon tax. The impact on GDP is much less pronounced than what it is on emissions. A tax with the proposed exemption regime, without the recycling of the revenue, is likely to reduce the GDP by 6.4% from the baseline, i.e. the 2035 level of what the GDP would have been without the tax. With a gradual phasing-out of all the exemptions, the reduction in the GDP is likely to be 13.7%. With tax recycling, the decline in the GDP is likely to be about 5%.

3. Should the tax not be recycled there could be an increase in renewable energy production of up to 291%. However, should the tax be recycled to support the renewable energy sector, renewable power generation could increase by 376%.

4. The sectors most likely to be affected are the coal-fired power generation sector, petroleum refineries, coke oven, and iron and steel industries. These are the energy intensive industries that also depend largely on coal or other carbon intensive inputs. In the case of iron and steel, for example, with no tax recycling, production may be reduced by as much as 39.5%. With recycling of the revenue through a subsidy on renewable energy, this decline is limited to 30%. Recycling the revenue through a reduction in VAT is likely to reduce production by around 24.2%.

The outcomes from the economy-wide modelling of the carbon tax are summarised as follows:

Table 2: Summary of results of the FutureWorks / University of Pretoria's 2015 economy-wide modelling of the proposed carbon tax

Carbon tax recycling alternatives	% change from baseline*			
	Emissions	GDP	Renewable electricity generation	Iron and steel
No recycling; existing exemption regime	38,3%	-6,4%	291%	
No recycling; gradual removal of all exemptions	50,1%	-13,7%		-39,5%
With recycling though VAT; gradual removal of all exemptions	40,7%	-5%		-24,2%
With recycling through support for renewable energy generation; gradual removal of all exemptions			376%	-30%

* Baseline = the level of the variable before the introduction of the tax

The implications of these results, nationally, are:

(i) The impacts of the carbon tax on emission reductions far outweighs the effect on GDP, and more so when considering the post-revenue recycling options. For example, there is a 3.7-fold difference between the change in emissions and the change in GDP under the 'no recycling with gradual removal of all exemptions' option (50.1% and 13.7%), and more than an 8-fold difference with tax revenue recycling (40.7% and 5%). The reduction in GDP is therefore much less with revenue recycling than the reduction in emissions achieved.

(ii) The impact on national GDP is mainly concentrated within a few very large and energy intensive sectors.

(iii) The recycling of the tax revenue, and how it is done, is a significant measure for reducing the potential adverse economic effects of the tax.

(iv) The renewable energy sector, with or without support *via* tax recycling, has much to gain from the introduction of a carbon tax.

2.3.6.4 Carbon Pricing Implications for the Western Cape Economy

It is extremely difficult to anticipate the exact form that the proposed National Carbon Tax is going to take, when and if it is to be implemented, and which revenue recycling option is going to be followed (if any).

The CGE modelling that has been undertaken in the current study has revealed that trade from the Western Cape is exposed to climate change impacts. These impacts include regulatory changes such as carbon pricing. A carbon price, whether applied globally or by South Africa (through a Carbon Tax), or *via* "Border Tax Adjustments[16]" would have differential effects, altering the comparative advantage of countries and regions, and the competitive advantage of sectors and firms. This, in turn, would affect global terms of trade and import and export patterns.

The WCG needs to anticipate and plan to secure the province's place in an increasingly carbon-constrained global economy.

While uncertainty regarding the South African carbon tax remains, a cursory glance at the assumptions applied in global climate models and international climate strategies is enough to suggest that carbon pricing is a likely feature of the global response to climate change. There is a growing number of countries, regions and companies applying carbon pricing, some to protect their domestic industries, others to advance their climate change strategies and credentials, and others to catalyse efficiency gains within their economies.

Modelling undertaken for South Africa's National Treasury (Van Heerden *et al.* 2016) shows that the proposed South African carbon tax, with no concomitant changes in relative prices abroad, would affect South Africa's trade balance negatively. The same effects would ensue from an internationally levied carbon tax. The underlying reason involves the relative carbon intensity of the South African economy (see Figure 15).

It is often assumed that exports from the Western Cape, which has relatively little mining or heavy industry, would be less exposed to international carbon pricing than other regions of South Africa. This is not necessarily correct. Van Heerden *et al.* (2016) revealed that the

[16] The World Trade Organization has given an in-principle agreement to such taxes, provided they are "non-discriminatory harmonizing tariffs" (Hillman, 2013).

sectors most-affected by the National Carbon Tax would be: Coal-Generated Electricity; Other Manufacturing; Petroleum Refineries; Coke-oven; and Iron and Steel. These sectors face an increase in their costs, which, if not carefully managed, would threaten their competitiveness. Not only does the Western Cape have several major petroleum refineries, the provincial economy also remains highly dependent on coal-fired electricity to support other manufacturing operations, including in the iron and steel industry, which would be highly exposed to carbon pricing.

The Western Cape economy could be negatively affected by national or global carbon pricing, with the most exposed sectors being petroleum refineries, and all high electricity consuming industries such as iron and steel manufacturing.

However, the Western Cape province could benefit from increased demand for renewable energy stimulated by local or global carbon pricing, given the WCG's proactive stance in promoting the development of this sector.

Proactive investment in the sectors that will benefit from a carbon tax would serve the strategic interests of the provincial economy.

In this sense, the Western Cape's trade exposure to local and global carbon pricing will hinge on several factors:

- The absolute carbon intensity of its export sectors;
- The carbon intensity of its export sectors relative to its competitors in South Africa and globally;
- The capacity to reduce the carbon intensity of specific sectors at reasonable cost;
- The impact of climate change on local productivity relative to productivity in competitor regions.

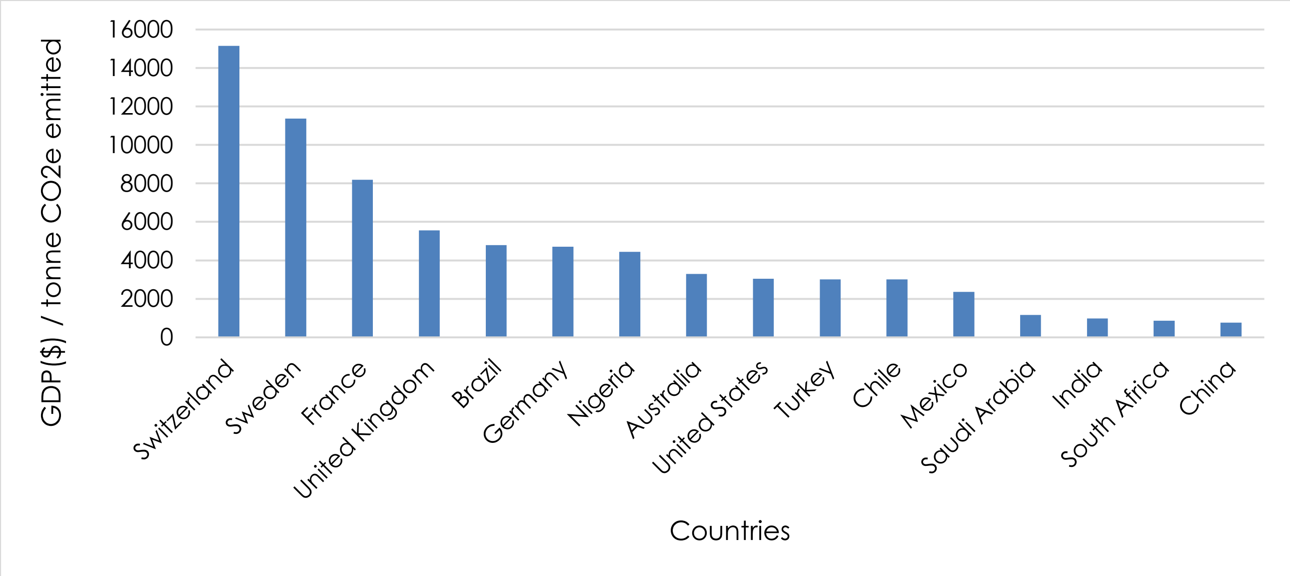

Figure 15: GDP ($) per ton of CO_2e emitted by country in 2013, revealing South Africa to be a carbon intensive economy by international standards (source: World Bank data, own calculations)

Worryingly for the Western Cape, South Africa has struggled to decouple its economic production from emissions relative to countries such as China (see Figure 16).

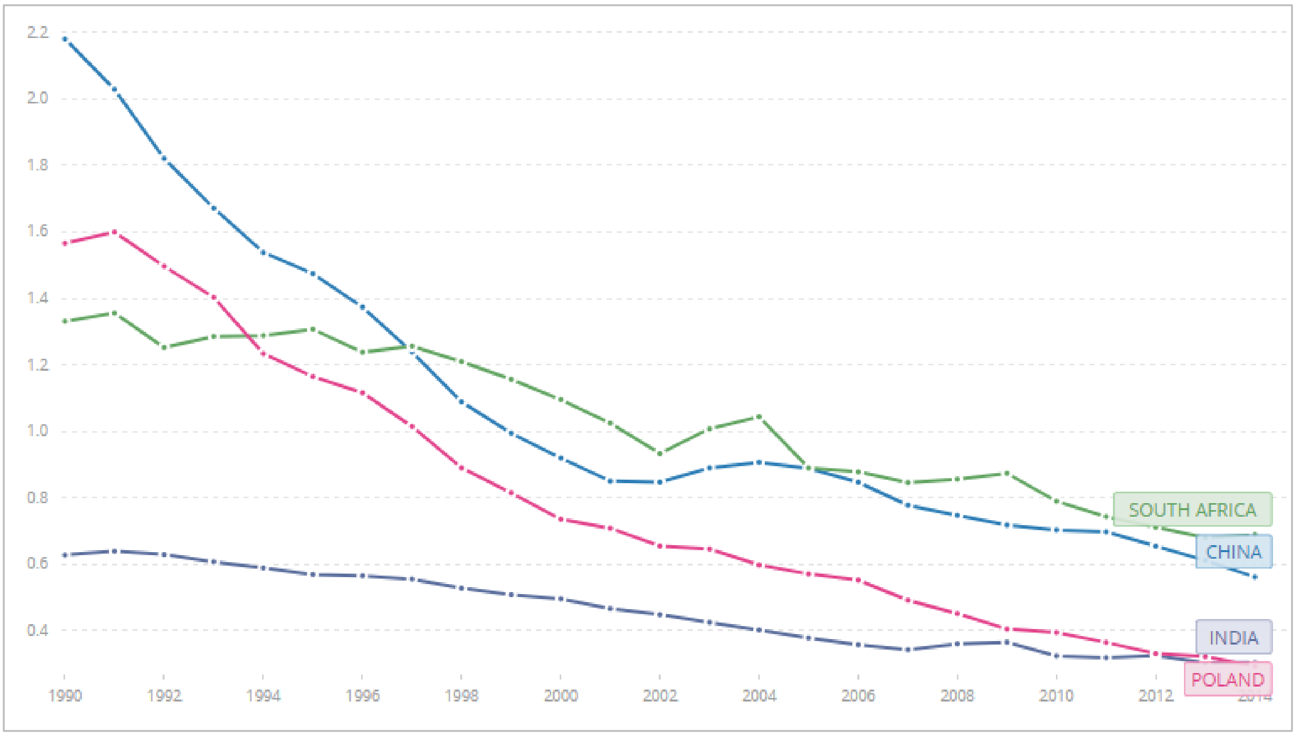

Figure 16: Relative decline of CO2e/GDP (2010 US$) 1990-2014, showing China's and India's progress in decoupling emissions from GDP relative to South Africa's and Poland's progress (source: World Bank data)

Work undertaken by the Theewaterskloof Municipality during the preparation of their Green Economy Strategy in 2009, for example, estimated that the additional cost imposed by a global carbon price of ZAR100 per ton of CO_2 on a kilogram of deciduous fruit exported from Cape Town to Europe, would be R0.20. The same tax would impose an additional cost of R0.06 to R0.11 per kilogram of fruit exported from Chile, one of South Africa's competitors in the global fruit industry[17]. The relative difference represents the straight carbon price impact between the two countries and highlights the different carbon intensities of production. The same work advocated for a widespread soil carbon programme that reduces the carbon intensity of fruit exports from the region, and a localised voluntary carbon market levied on tourism bed-nights.

One option available to the Western Cape for reducing such trade impacts involves applying a provincial or sector-wide carbon tax as part of its climate resilience response. Exports from the Western Cape would then only incur additional taxation if importing countries had a higher rate than that imposed by the Western Cape - the so-called Border Adjustment Tax. Care would have to be taken to ensure this did not compromise the province's economy in terms of rendering essential imports more expensive and increasing the cost of exports from the province. Such a tax would, however, prepare the provincial economy for the inevitable transition, raise revenue for the provincial fiscus and encourage investment in low carbon sectors, something that the WCG aspires to in its economic strategies.

[17] www.twk.org.za/download_document/388

3 COST-BENEFIT ANALYSIS OF WESTERN CAPE CLIMATE CHANGE RESPONSES

3.1 The Cost-Benefit Analysis Approach

The economic modelling undertaken in an earlier phase of the "Assessment of Economic Risks and Opportunities of Climate Resilience in the Western Cape" study revealed that in the absence of adaptation, anthropogenic climate change will impose an economic burden on the Western Cape Province of South Africa. The same analysis suggested that a proactive response to climate change could attract investment, skills and labour to the province, thereby generating economic development.

This finding concurs with work conducted in other countries suggesting that the economic threat of climate change can provide a catalyst for green economic growth and development (Rode *et al.* 2015; Colenbrander *et al.* 2016).

Turning climate change responses into an economic and development benefit, requires good decisions regarding which options are most likely to succeed in different contexts. Climate change responses take multiple forms and are not equally effective or equally priced. In the context of constrained public resources – both money and people – it is important to identify those climate change responses that deliver the greatest benefit per unit of public expenditure.

CBA is the conventional tool with which to rank multiple options in terms of 'bang for buck' in the context of limited resources (High-Level Commission on Carbon Prices, 2017). Climate change CBAs have typically juxtaposed the amount of climate change damage that is avoided by a climate response (i.e. the 'benefit') and the cost of that response. This method of conducting CBAs, relies on a "damage function" that maps the relationship between the loss of GDP in the absence of any climate change response and rising temperatures (Figure 17). Only once this relationship is understood, can the benefit of the avoided damage be attributed to a particular climate change response.

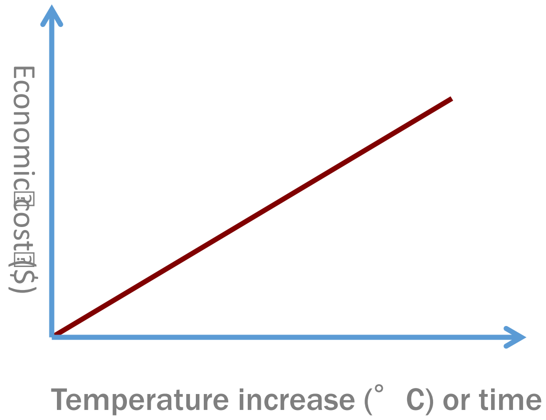

Figure 17: Conventional damage function, as applied in economic modelling, reflecting the relationship between temperature rise and the cost of climate change

The history of climate change CBA research has been important in highlighting climate change responses that can save money in the short-term, others that require up-front investment to reduce damages at a later stage, and other options for which there is no obvious financial rationale, but which might be considered worthy for reasons other than a quantifiable return on investment (Hallegatte et al., 2017).

The same work has been criticised because of analytical uncertainties concerning how, where and when climate change impacts will manifest, and the complexity of modelling the effectiveness of climate change responses in reducing these impacts (Stern 2016). These difficulties arise from the non-linear relationship between temperature change and damage, and the fact that both impacts and responses may manifest over variable spatial and geographic scales which are difficult to monitor and quantify. In addition, climate change damage is highly subjective and difficult to aggregate, especially across different socio-economic profiles. These analytical problems and subjective perceptions of the severity of climate change damage results in the need to use "discount rates[18]" when modelling the costs and benefits of climate impacts and responses.

Conventional CBAs are further complicated by the limitations of Gross Domestic Product (GDP) as a proxy for benefit, and the associated biases that the use of this proxy introduces. GDP's inability to reflect the value of environmental assets, the social cost of inequality or the impact of externalities such as pollutants, render it limited as a means of reflecting what households value in the context of climate change (Cartwright et al., 2013, Stern, 2016). CBAs that rely exclusively on GDP may, for example, end up prioritising the value of

[18] A "discount rate" refers to the time value of money. The higher a discount rate is, the higher the depreciation of the value of money over time (or, money loses its purchasing power over time). The lower a discount rate, the slower money loses its purchasing power relative to today. Discount rates are intended to capture human behaviour and particularly the perceived risks of the future – the higher the perceived risk the more people prioritise the current period and the higher the discount rate.

expensive property, private infrastructure or valuable businesses based on their contribution to economic growth (and GDP), at the expense of options that save lives of economically inactive people, or safeguards shack dwellers who don't make as significant a contribution to GDP but are highly vulnerable to climate impacts.

In the likely event that climate change damage functions take on non-linear and non-continuous forms that are more accurately presented by Figure 18, conventional CBA becomes more difficult and relying on a GDP based damage function can produce inaccurate and perverse results.

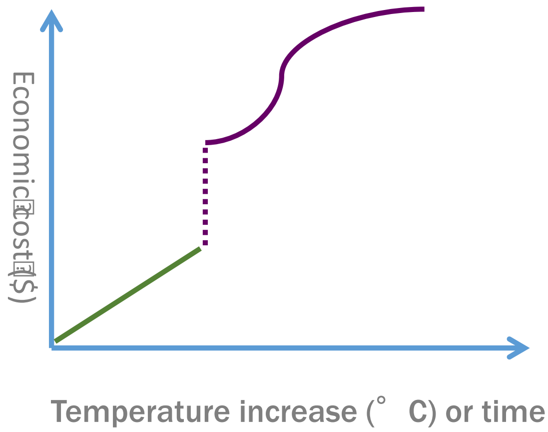

Figure 18: More likely damage function depicting the relationship between temperature rise and economic loss, depicting an abrupt discontinuity and making economic modelling more complicated

This does not detract from the need that all public entities confront in prioritising options within their budgets, but it does warrant new approaches to CBA in the context of climate change in developing countries. This is particularly the case in places such as the Western Cape where inequality and poverty are a feature. In these contexts, the State has a duty to look beyond narrow economic interests and consider socially marginalised people and the public goods such as environmental assets and knowledge institutions that narrow commercial interests in a market-based economy tend to ignore.

3.2 Methodology

3.2.1 The use of Cost-Benefit Analysis

The CBA process in this study sought to take account of the analytical difficulties discussed in the previous section. The analysis began from the premise that high-levels of informality and inequality in conjunction with uncertainty around the timing and full social, economic and ecological impact of climate change in the Western Cape, made it impossible to compile a single, linear, damage function. In addition, exclusive reliance on a GDP-based damage function was recognised as being unsuitable for a public entity mandated to safeguard more than narrow economic interests. Specific efforts were made not to conceal differences in perceptions, and experiences, of climate change risk where these differences exert a definitive influence on society. This premise, combined with uncertainty regarding the efficacy of adaptation efforts, rendered it unwise to apply "avoided GDP loss" as the exclusive proxy for "benefit" in a CBA of climate change responses. To address conventional CBA limitations, but provide useful decision analysis for the provincial government, the study introduced a series of innovations and these are discussed in Sections 2.2 and 2.3 below.

3.2.2 Identifying Climate Change Responses for Analysis

The first step in the CBA process involved identifying existing or planned government responses to climate change in the Western Cape, particularly those considered most relevant or important for addressing existing climate impacts. Public officials in the WCG, the City of Cape Town, and in supporting agencies such as GreenCape and Wesgro, were asked to identify potential climate change responses that aligned with the following criteria:

- **Falls within the WCG mandate or sphere of influence.** There are many good climate change responses, but they are not all the responsibility, or within the influence, of provincial governments under South Africa's constitutional allocation of mandates across its three spheres of government.
- **Actionable within the next five years.** This requires there to be both the capacity to implement as well as the realistic possibility of being able to finance the climate change response within the next 5 years.
- **Reduces climate risk, enhances climate resilience or reduces greenhouse gas emissions.** While the systemic nature of climate change impacts was acknowledged, this criterion remained important given the focus of the study.
- **Scalable or capable of have a significant impact on climate resilience in the province.** This excludes projects that are specific or limited to a single household or a confined location.
- **Capable of securing political buy-in.** This was considered important for implementation, and to reflect the influence of social acceptability.
- **Supporting job or work creation, poverty alleviation and a reduction in inequality - all of which are important within the context of the Western Cape.** Capable of delivering other co-benefits, including ecological rehabilitation, reduced financial dependence on the State, reduced inequality and social cohesion.

An initial list of 68 current and planned climate change responses in the Western Cape was developed. Together with government officials, and using the above criteria as a guide, this list was narrowed down to 16 responses that would be analysed in the CBA (see Table 3). A critical consideration in developing this short-list was the availability of reliable project cost and impact data. Where promising climate change responses did not have these data, they were not short-listed for analysis.

Table 3: Summary of 16 climate change responses evaluated in the CBA

Climate Change Responses
Conservation Agriculture A programme run by the Western Cape Department of Agriculture, with support from the National Department of Agriculture that promotes reduced tillage, mulching and the use of cover crops to enhance soil carbon and water retention in the soil. This is considered particularly helpful in a drying climate. It is assumed that Conservation Agriculture impacts on 80% of the Western Cape population, primarily through stabilising staple food prices.
Fruitlook Fruitlook is a precision farming farmer support programme implemented by the Western Cape Department of Agriculture. The programme enables more accurate crop watering and fertiliser use, resulting in less water use and better yields.
LandCare Landcare is a community works programme funded by national government but manged by the provinces, aimed at countering the impact of erosion and soil degradation. Teams of people working for the Landcare programme rehabilitate dongas and gullies that would otherwise lead to accelerated erosion and loss of topsoil, particularly during high rainfall events.
Agricultural Disaster Management Agriculture disaster relief is a reactive measure provided from the national or provincial fiscus once a natural disaster has been declared for the agricultural sector. Historically, crop and livestock losses caused by drought, flood and hail have been the reasons for mobilising disaster relief and management.
Upgrading Informal Settlement Programme The informal settlement upgrading programme run by the Provincial Department of Human Settlements, works with residents in informal settlements to map the lay-out of housing units, use more resilient building material and provide services such as water, sanitation and energy.
Desalination: Large Large scale desalination refers to any project capable of delivering over 50 million litres of potable water per day. The modelling for this study was based on the cost of providing 220 million litres of potable water per day.
Desalination: Small (Harmony Park) Modelling of small-scale desalination in this study was based on the Harmony Park project under construction in False Bay. The project will produce 8 million litres of potable water per day.
PV on government buildings The installation of photovoltaic (PV) and monitoring technologies on buildings owned or occupied by provincial government to reduce greenhouse gas emissions and reduce the money paid to Eskom (via the local municipality in some instances) for electricity. The falling cost of photovoltaic electricity results in these installations saving the provincial government money over time.
Water re-use (50Ml / day) Re-using waste water by using reverse osmosis technology to augment the supply of potable water. The model reflected a planned 50 million litres per day project in Cape Town.
Atlantis SEZ An existing project that creates a Special Economic Zone (SEZ) near the dormitory town of Atlantis in which new businesses enjoy agglomeration benefits, green energy, water recycling and concessionary tariffs and rentals. The demarcation of such a zone required investments by provincial and national government.

Hout Bay recycling co-op roll-out The roll-out of waste diversion sites run by community-based co-operatives that sort, recycle and upcycle waste from municipal waste streams. These sites reduce waste to landfill, create employment and reduce greenhouse gas emissions.
BRT - Phase 1A The first phase of the City of Cape Town's Bus Rapid Transit (BRT) system, costing R4 billion, and servicing the Atlantis Corridor and Inner City.
Mbekweni artificial wetland Construction and maintenance of a wetland to assist in the remediation of industrial effluent from Mbekweni before it enters the Berg River near Paarl.
Berg/Breede upper catchment invasive alien plant clearing National Department of Public Works programme aimed at removing invasive alien tree species from water catchments that supply water to the City of Cape Town, adjacent municipalities and farmlands.
Boreholes (hospitals & schools) Installation of groundwater abstraction facilities, water meters and filters at hospitals and schools to ensure that these public facilities can cope in the instance of severe drought.
GreenCape A special purpose vehicle aimed at generating new research and business support capacity that positions the Western Cape as a global leader in the global green economy and attracts the investment that accompanies this growing economy to the Western Cape. This agency is considered a key driver and facilitator of climate change response interventions at an economy-wide scale in the province.

3.2.3 Applying the Cost-Benefit Analysis

As a first step, the following assumptions were developed for the CBA model:

- The term over which the model is run: 25 years was selected for use in the current CBA model.
- A discount rate[19] that could be applied to capital and operating costs incurred by the respective climate responses. In this analysis a 1% discount rate was used to reflect a government which places high value on the future.

The second step involved scoring each of the 16 climate change responses for "intrinsic merit". Each option was scored by government officials in terms of its ability to:

- Improve adaptation to climate change impacts;
- Mitigate emissions;
- Contribute to economic development; and
- Contribute to general societal well-being.

[19] A "discount rate" refers to the time value of money. The higher a discount rate is, the higher the depreciation of the value of money over time (or, money loses its purchasing power over time). The lower a discount rate, the slower money loses its purchasing power relative to today. Discount rates are intended to capture human behaviour and particularly peoples' perceived risks of the future – the higher the perceived risk the more people prioritise the current period and the higher the discount rate.

These criteria were disaggregated into 10 sub-criteria that were used by officials to score each of the 16 climate change responses for intrinsic merit. This notion of merit sought to align with the mandate and strategic purpose of the Western Cape Department of Environmental Affairs and Development Planning. The scoring for intrinsic merit in this step was independent of the scale and cost of the climate response.

The third step in the model involved calculating the costs of each response option. This was relatively straight-forward and included public expenditure across all three spheres of government. A combination of actual costs contained in existing budget data, contracted costs in newly procured projects and anticipated costs was used to compile the cost of respective climate responses. These data were sourced from government documents and a series of interviews with officials. For each response option, capital and operating costs were gathered and imputed over the lifetime of the project. The period over which capital costs were expended was important to the cost calculation and had to be inserted in the model. So too was the year in which the project would start, or had started, and the project end-date. The net present value of costs was calculated based on these temporal considerations of expenditure, using a discount rate that can be altered to reflect the decision-makers perception of the future.

The fourth step involved calculating the benefits. This was more complicated given the decision not to focus exclusively on avoided GDP loss. Calculating benefits required the model-user to estimate the number of people positively impacted by each climate change response option, and to discern the degree of positive impact on respective sub-portions of the population.

The degree of positive impact was dis-aggregated into the following impact categories, and weighted accordingly:

- Life-saving impact weight = 1
- Life improvement impact weight = 0.3
- Moderate impact weight = 0.07
- Very little impact weight = 0.03
- **Total weight = 1.4**

The positive impact was estimated based on the influence of the climate response over a 25-year period of analysis, in the context of anticipated climate change.

The respective weightings were multiplied by the total number of people exposed to each level of impact as a result of the climate response. The composite of these weighted population numbers provided a "population impact factor". For example, where a particular climate change response was expected save 100 lives, this could generate a "population impact factor" of 100. If the same response were to have a moderate life improving impact on 100 people, this would generate a score of 7.

The "population impact factors" for all four categories of impact were aggregated for each climate change response, to provide an aggregate "population impact factor" for each climate response. Benefits were not discounted in the model due to the propensity for discounted indices to produce inconsistent results.

The fifth step involved multiplying the aggregate "population impact factor" of each response option by the weighted "intrinsic merit" score assigned to each response option by officials, to generate a proxy for benefit that is called the "Human Benefit Index" (Cartwright *et al.* 2013). This metric of benefit includes more factors that are important to good decision making in the context of climate change in the Western Cape than an estimate of avoided GDP loss.

The sixth and final step involved comparing the costs of each measure with the "Human Benefit Index" score for that measure. This comparison provided a cost to benefit ratio that could be interpreted as the cost, in present value terms, that is required to generate 1 unit of benefit in the context of climate change.

This approach to conducting a CBA was deliberate in seeking to address some of the documented limitations of conventional climate change CBA (Cartwright *et al.* 2013; Stern, 2016). The advantages of this approach include:

- It recognises that provincial government is mandated to be developmental and to pursue a notion of "benefit" that involves more than avoided GDP loss and instead speaks to the public good.
- It includes both adaptation and mitigation responses, and can accommodate projects, programmes and more systemic climate responses involving institutional reform or ecological rehabilitation.
- It puts people and their well-being at the centre of the metric for "benefit" and recognises the importance of employment creation, for example, as part of effective climate responses.
- It introduces multiple criteria into the notion of benefit and requires public sector decision makers to engage this set of criteria, thereby forcing them to consider issues that may not be directly related to their position, but which remain in the public's interest in the Western Cape.
- Whilst the analysis does not explicitly include a criterion related to ecological degradation or inequality, these factors can be introduced by officials in the weighting and scoring of response options for "intrinsic merit".
- It provides a long-term analysis – 25-year time horizon as a default value - but can accommodate different time horizons.
- The analysis can accommodate different discount rates to reflect the very different views of the future, and risk aversion, of people in the Western Cape.

3.3 Results

The results of the CBA model are reported as cost to benefit ratios. These are shown in ranked order in Table 4, where the lower the ratio, the more economically efficient the climate change response measure is.

Table 4: Ranked summary of CBA results (over 25 years)

Climate change response	Human Benefit Index	Discounted cost (R'000)	Cost-Benefit ratio
Rooftop PV on gov. buildings	129 417	-597 029	-4,61
Conservation agriculture	3 073 304	126 920	0,04
Berg/Breede upper catchment	1 700 126	114 969	0,07
Hout Bay recycling co-op roll-out	70 004	10 393	0,15
Mbekweni artificial wetland	126 007	25 944	0,21
Fruitlook	732 930	199 189	0,27
LandCare	583 364	506 533	0,87
Boreholes (Hospt & schools)	916 437	954 793	1,04
Agric. disaster management	1 106 350	1 651 737	1,49
Atlantis SEZ	163 474	246 299	1,51
Water re-use (50Ml/day)	1 253 545	4 019 226	3,21
Upgrading Informal Settlement Programme	2 418 578	8 544 984	3,53
BRT - phase 1A	951 504	8 287 376	8,71
Desal: Large	4 546 189	42 269 083	9,30
Desal: Small (Harmony Park)	129 672	1 607 690	12,40

It is clear from Table 4 that installing PV technologies on government buildings ranks "best" as a climate response amongst the 16 options evaluated in the CBA model. This is followed by the existing conservation agriculture programme, the removal of invasive alien species from critical water catchments, and the roll-out of labour intensive solid-waste recycling measures.

Figures 1 and 2 depict the same results in the form of a "climate change response cost curve". The width of the columns in Figures 1 and 2 reflect the Human Benefit Index score, while the height of each column is inversely proportionate to the cost-benefit ratio, i.e. lower is better.

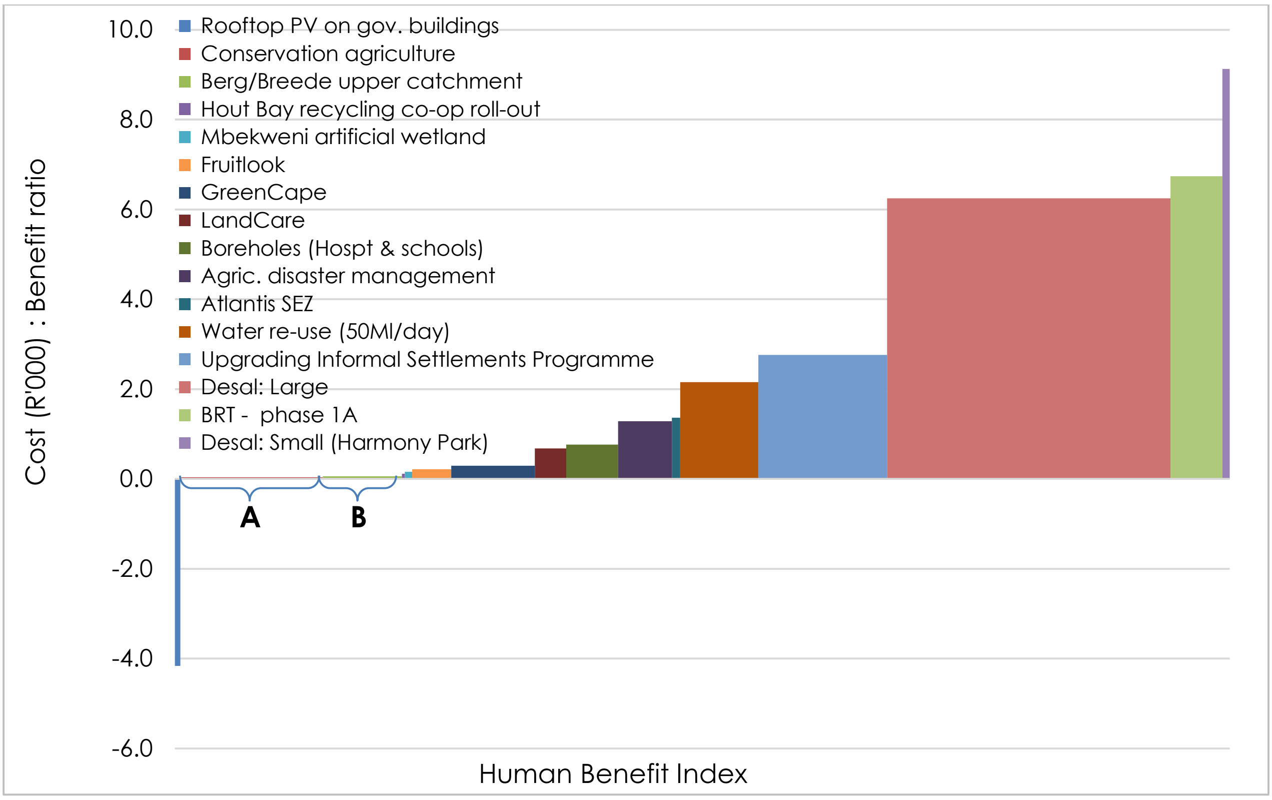

Figure 19: Summary of CBA results for the 16 climate change responses (note the blank space occupied by conservation agriculture (A) and invasive alien plant clearing in the Berg/Breede upper catchment (B), which have a cost-benefit ratio that is not visible relative to the horizontal axis)

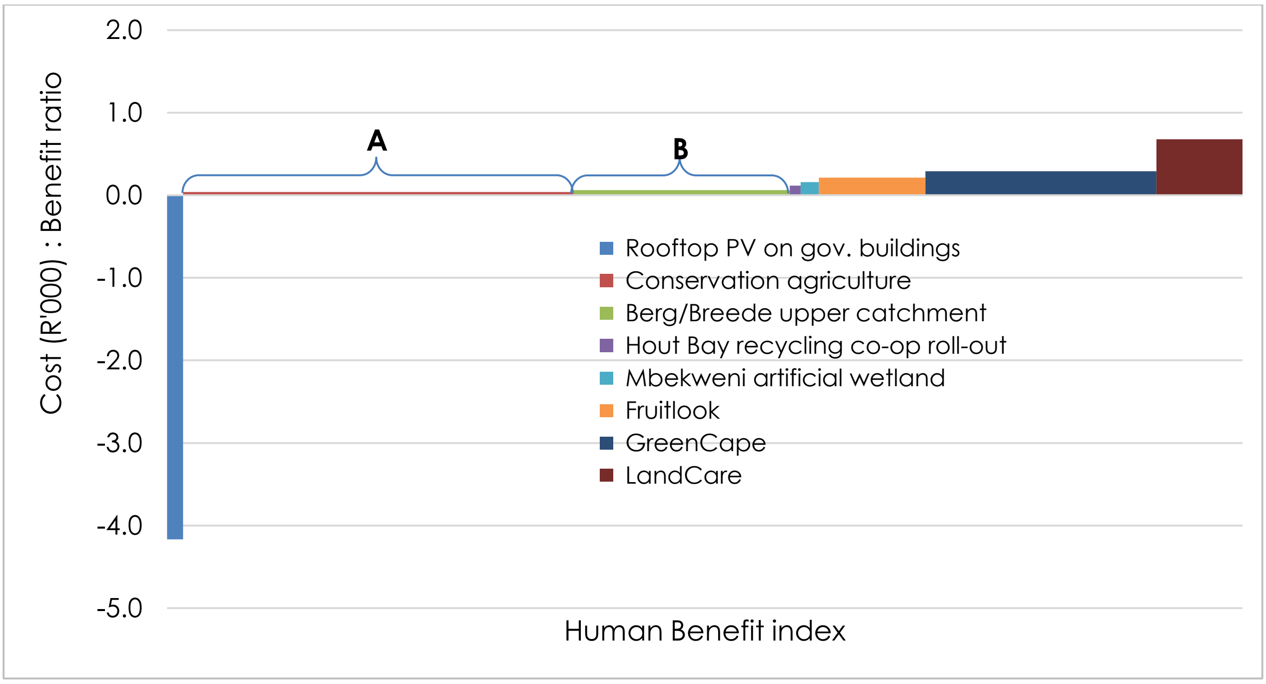

Figure 20: The eight climate change responses with the best cost-benefit ratios, where the height of the bar reflects the cost per unit of benefit, and the width of the bar the magnitude of the Human Benefit Index (note the blank space occupied by conservation agriculture (A) and invasive alien plant clearing in the Berg/Breede upper catchment (B), which have a cost-benefit ratio that is not visible relative to the horizontal axis)

Figures 1 and 2 show that the installation of PV technology on government buildings reduces current expenditure while responding to climate change. The 15 other responses present varying degrees of cost-effectiveness. From the perspective of financial efficiency, the CBA results could be used to prioritise project implementation from left to right on the graph. However, the level of human benefit of each option should also be considered, and therefore this prioritisation process may be more complex.

When interpreting these results, it's important to bear in mind that money is not the only consideration when choosing which climate change responses to prioritise for implementation. The kinds of benefits created are also a key consideration, with some benefits addressing immediate climate risks and others focused on long-term resource security or greenhouse gas emissions reductions. As a tool, the CBA model does not take decisions, and it does not replace the responsibility and obligation on senior management within the WCG to manage these difficult trade-offs in reducing climate change risk and impacts.

Even for the money-saving climate change response, it remains the case that the money must be reallocated or borrowed from some or other allocation to implement the project. It is worth noting, however, that cost-effective climate change responses can be found across a range of sectors and departments, underscoring the observation that reducing climate change risks is a province-wide responsibility and not the domain of a single department or unit within the WCG.

The various economically attractive climate change responses that emerged from the CBA modelling include both adaptation and emissions mitigation actions, emphasising the importance of both. Many of the best performing climate change responses are programmatic in the sense that they address the functioning of an entire system – e.g. energy regimes, soil, ecological health, information and knowledge – as opposed to a single problem. From this it seems clear that climate change responses that alter socio-technical (Geels *et al.* 2016) or socio-ecological (Cote and Nightingale, 2012; Daron *et al.* 2014) systems, as opposed to addressing a discrete problem, offer good value for money. Within the context of the Western Cape, climate change responses that offer work creation, developmental or ecological co-benefits emerge as economically attractive and cost effective.

It is equally notable that large infrastructure projects (e.g. BRT and desalination) perform poorly in the model due to the high cost of their construction. There may, however, be other important reasons why the high costs of these projects are justified: they offer visibility and assist in instilling confidence in an anxious public, they are familiar to the government procurement teams and present the types of 'known risks' (such as late delivery or budget over-runs) that the government has evolved to accommodate. Where public authorities push ahead with these types of projects, they must be able to indicate that they are familiar with the foregone opportunities and have a rationale (other than CBA) that is defensible. In this way, the CBA findings do not, and should not, preclude these projects, but rather enable their planning within the broader fiscal and climate change context.

Despite its innovations, the CBA model has some limitations that are important to note. It remains very difficult to include all costs, especially the costs imposed by climate change if no responses are mobilised by the provincial government. The first phase of the "Assessment of Economic Risks and Opportunities of Climate Resilient in the Western Cape" study (involving economic modelling) revealed that climate change, if left unchecked, is expected to damage the Western Cape economy, but this finding is not imputed in the CBA analysis of response options.

Similarly, it is difficult, despite the model's best efforts, to incorporate all benefits, particularly when these benefits manifest over incommensurate pathways and timeframes, e.g. ecological restoration (invasive alien plant clearing), versus informal settlement upgrading, versus knowledge generation (GreenCape). The value of a cubic metre of water produced from desalination, for example, depends on the availability of water more generally. This is something that varies over time.

The model does allow for the disaggregation of cost and benefit, as well as the multiple components of benefit to provide specific insights. It is therefore possible to discern a priority ranking that is based on benefit alone. This might apply if the WCG were not operating under budget constraints, or if it was required to solicit donor funding for the greatest impact.

4 THE ECONOMIC RISKS AND OPPORTUNITIES OF CLIMATE CHANGE AND CLIMATE RESILIENCE IN THE WESTERN CAPE

4.1 Global Climate Change and the Economy

Anthropogenic warming of the atmosphere, which now exceeds 1°C above pre-industrial (1850-1900) levels and has a high probability of exceeding 1.5°C shortly after the middle of this century, is "extremely likely" (in the conservative probabilistic language of the IPCC) to be linked to the accumulation of greenhouse gases in the atmosphere (IPCC, 2014). Once natural variation and the influence of volcanoes is stripped out, the accumulation of greenhouse gases has, to date, been driven by the burning of fossil fuels, the production of cement and the land use changes that release soil and forest carbon into the atmosphere.

As the climate warms, there is the distinct possibility that long-standing vaults of greenhouse gases in ice, soil and the oceans will be released into the atmosphere, causing run-away climate change when positive feedbacks reinforce the warming trend and render mitigation efforts associated with reducing fossil fuel consumption less significant on the warming trend. The imperative of avoiding catastrophically dangerous climate change, places emphasis on the economic activities that are principally responsible for the emissions of greenhouse gases.

Greenhouse gas emissions have historically been closely correlated with economic growth and resource consumption. In the past five years some countries have managed to decouple emissions (and resource consumption) from economic growth, but South Africa is not amongst these countries.

Existing anthropogenic warming and associated climate change has already begun to impose an economic cost, through greater frequency and intensity of weather related disasters, disruptions in the supply of water and energy and shifting disease vectors (Stern *et al.* 2006; Nordhaus, 2013; IPCC, 2014). A further class of costs has been linked to the reallocation of capital, the closing down of carbon intensive industries and greater expenditure on disaster responses and insurance. Ultimately the cost of climate change has to be manged through the removal of all anthropogenic emissions, a situation that would see further temperature increases stabilise within a decade (and would be indistinguishable from natural variability over that decade). This would not curtail sea-level rise and other impacts that rely on cumulative emissions, which could get worse for as long as a century after emissions drop to zero. In the interim countries, cities, companies and citizens are required to adapt to climate change, a challenge that has historically been cast as an additional cost.

The assumption that climate change mitigation and adaptation necessarily has to impose additional costs, has been challenged in recent years. Evidence from a number of regions, but particularly within developing country contexts, has shown that both the challenge of cutting emissions and the need to adapt to climate impacts can generate new (and better) growth pathways (Stern, 2013, 2015; Colenbrander *et al.* 2016). This research suggests that, where governments, the private sector and civil society respond proactively and coherently to the challenge of climate change, this could provide the catalyst for investment in low-carbon programmes and climate change adaptation projects that could not only be cost-saving and lower systemic risks and the likelihood of "stranded assets" – i.e. capital intensive assets that are rendered obsolete by climate change (Safarzyńska and van den Bergh 2017), but could also unlock new economic and development opportunities (GCEC, 2014).

This mode of climate response involves both the public and the private sector. However, the externalities of greenhouse gas emissions and associated market failure, creates a very specific responsibility on government to intervene and to enable private sector responses.

4.2 How Climate Change and Investment in Resilience could impact the Western Cape Economy

The WCG has a proud track-record of proactivity when it comes to climate change. In the latest iteration of this tradition, the "Assessment of Economic Risks and Opportunities of Climate Resilient Investment" study, the WCG sought to understand the economic cost of climate change on its economy, as well as the climate response options that might turn these costs into a growth opportunity. The analysis focussed on five 'sectors' that form the core of the provincial economy: agriculture, water, energy, transport and construction.

The results of the economic impact modelling revealed that climate change could, if ignored, contract the Western Cape's GDP by more than 17% by 2040. This result is driven by climate impacts that result in the province losing its workforce and investment to neighbouring provinces that adapt more effectively. The same effects would lead to a reduction in household incomes and increased cost of living in the Western Cape.

Consistent with the global narrative, the study analysis showed that were the WCG to use climate change as the signal to mobilise investments in effective climate responses, it could actually boost the provincial economy by 15% above the baseline by 2040.

This result would rest on the successful assimilation into the economy of people moving to the Western Cape to escape climate impacts in neighbouring provinces of South Africa.

The same proactive response to climate change in the Western Cape would increase regional exports 6.4% and international exports by 1.5% as the downward pressure on salary and labour prices caused by an influx of people and the relative lack of economic disruption, combine to enhance economic competitiveness. Competitiveness would simultaneously lower the cost of living and improve household incomes.

While the relative climate adaptation response between provinces in South Africa drives short-term economic prospects, suggesting a competitive element between provinces in the manner in which they respond to climate change, in the longer term (including beyond 2040) the WCG will require other provinces to adapt well to climate change to sustain their economies and demand for goods and services produced in the Western Cape. In this sense it is in the Western Cape's interests to collaborate with National and other Provincial Governments in co-ordination and sharing climate responses.

Proactive investment in climate resilience in the Western Cape can increase household incomes and make the cost of living lower. This is potentially a major driver of GDP growth and increased quality of life in the province.

4.3 Making informed Investment Choices for Positive Climate Resilience, Economic, Social and Developmental Outcomes

The economic modelling results painted a clear set of possible economic futures for the Western Cape under conditions of high and low climate change impact. Regardless of the level of climate impact, however, a future in which the WCG does not invest adequately in climate resilience will be accompanied by a rapidly declining economy, loss of human capital to regions less economically impacted, escalating unemployment and cost of living, increasing inequality and declining quality of life. However, proactive investment in climate resilience will lead to above-baseline economic growth, reduced levels of unemployment, stable commodity prices and cost of living, increasing human capital and reduced levels of inequality.

Turning government and private sector investments into enhanced climate resilience, and the abovementioned economic, social and developmental benefits requires good decisions regarding which options are most likely to succeed in different contexts and produce the type and scale of benefits desired. Climate change responses take multiple forms and are not equally effective or equally priced. In the context of constrained public resources – both money and people – it is important to identify those climate change responses that deliver the greatest benefit per unit of public expenditure.

However, it is also important to recognise that not all benefits derived from investment in climate resilience are equal. The types of benefits, the timescales over which the benefits accrue, the economic sectors and / or parts of the population that benefit, and intensity of the risk / impact that the responses address, may all differ significantly. It is therefore important that decision-makers consider the nature of the costs alongside the nature of the benefits when deciding which climate change responses to prioritise, and not just simply base decisions on least-cost or best cost-benefit ratio.

It is for this reason that CBA should be used as a decision-support tool, rather than a decision-making tool. The process of populating and running the CBA model can be useful as a convening tool for conversations and perspectives that force officials to think about the system in which they operate.

The CBA illustrated clearly how climate change responses might differ in terms of their costs and benefits. The 16 climate change responses evaluated fell into three broad categories:

1. **Built capital responses** (e.g. desalination, BRT, PV installations, etc.), These are responses that invest primarily in engineered infrastructure in order to address a particular aim or risk / threat. These may be focused on climate adaptation or emissions reductions, or on reducing resource dependency over time as a resilience response.

2. **Institutional capital responses** (e.g. GreenCape, Fruitlook, etc.). These are investments in building the capacity of people or institutions to invest in climate change responses or to become more resilient to climate change impacts.
3. **Natural capital responses** (e.g. Berg/Breede upper catchment invasive alien plant clearing, Conservation Agriculture, etc.). These are investments in ecological infrastructure as a mechanism for reducing climate change related risks, and enhancing the resilience of ecosystems to deliver critical goods and services under conditions of climate stress.

The CBA resulted showed that the built capital responses offered some of the greatest benefits by impacting a large proportion of the population and being highly effective in delivering climate resilient services (usually each built capital investment was focused on delivering one specific service). However, despite their important benefits, these responses were some of the most expensive to implement. An exception was the project involving PV installations on government buildings, which, although requiring capital investment upfront, will actually save government money over the medium to long term due to reduced energy costs.

Investing in built capital as a climate change response may, in certain situations, be the easiest and most socially acceptable way to address a critical service risk or issue (for example the need to implement desalination as an emergency response to water shortages in Cape Town during the prolonged drought of 2014-present). In such instances the high cost may be justified in order to achieve the required benefits.

The institutional capital responses also offered some of the greatest benefits, but at relatively lower cost than the built capital responses. These responses tended to have good cost-benefit ratios, as they are not expensive to implement and can impact large numbers of people through leveraging broad-scale action and / or investment in the green economy / climate resilience.

Natural capital responses, like the built and institutional capital responses, were shown to be capable of delivering a high magnitude of benefits to a large proportion of the population, but for a relatively low cost. In comparison to built capital costs, natural capital already exists (and doesn't have to be built) and requires only maintenance costs. Consequently, natural capital responses emerged as some of the least-cost responses in the CBA. In many instances the restoration and maintenance of natural capital offers the type of work that unemployed people in the Western Cape can undertake: it is local, relatively low skilled and linked to a sense of place that imparts a valuable sense of identity. It is also not the type of work that can be easily removed by quixotic shifts in global markets.

Many of the best performing climate change responses are therefore programmatic in the sense that they address the functioning of an entire system – e.g. energy regimes, soil, ecological health, social, information and knowledge – as opposed to a single problem.

From this it is clear that the co-benefits of specific climate responses represent a crucial consideration, and climate change responses that alter social-technical (Geels *et al.* 2016) or social-ecological (Cote and Nightingale, 2012; Daron *et al.* 2014) systems, as opposed to addressing a discrete problem, offer good value for money.

Within the context of the Western Cape, climate change responses that offer work creation, developmental or ecological co-benefits emerge as economically attractive and cost effective.

The CBA used several factors to produce a "Human Benefit Index" as a measure of benefit. A component of this calculation was a ranking of the 'intrinsic merit' of each climate change response, which was provided by an expert group in a workshop setting. The intrinsic merit score included a ranking of how well each response was thought to be capable of delivering the following outcomes: climate change adaptation, carbon emissions reductions, economic development, and enhanced human well-being. Table 5 shows that there are significant differences in the types of benefits that each response is expected to deliver. This is an important nuance that decision-makers looking to prioritise climate change responses need to take into account in addition to the overall cost-benefit ratios.

Table 5: Intrinsic merit scores allocated to each of the 16 climate change responses evaluated in the CBA (high score and green colour indicates high merit, low score and red colour indicates low merit)

Criteria	Adaptation to climate change impacts	Mitigation of carbon emissions	Economic dev.	Well-being	Total	Built	Institutional	Natural
GreenCape	2.5	4.2	4.5	3.9	3.52		X	
Mbekweni artificial wetland	2.8	2.8	4	3.8	3.24			X
Upgrading Informal Settlement Programme	3.8	1.6	3	3.9	3.22	X		
Berg/Breede upper catchment	3.5	0.8	4	3.8	3.12			X
LandCare	2.7	2.6	3.5	3.5	3			X
Conservation agriculture	3.1	3	2.5	2.4	2.82		X	X
Hout Bay recycling co-op roll-out	2	2.4	3	4.1	2.7	X		X
Fruitlook	2.6	1.8	4	2.4	2.68		X	
Atlantis SEZ	1.7	1.8	4.5	2.3	2.4	X		
Boreholes (Hospt & schools)	2.9	0	2	3.4	2.24	X		
Water recycling (50Ml/ day)	2.6	0.6	3.5	1.5	2.16	X		
Desal: Large	2.6	0	3.5	1.5	2.04	X		
Desal: Small (Harmony Park)	2.6	0	3.5	1.5	2.04	X		
BRT - phase 1A	0.3	3	2.5	3.4	1.9	X		
Rooftop PV on gov. buildings	0.6	3	4	1.3	1.9	X		
Agric. disaster management	2.7	0	1	1.2	1.52	X	X	

Table 5 also shows that there was a tendency for the institutional and natural capital climate change responses to score higher in terms of 'intrinsic merit' than the built capital projects.

There are thus distinct nuances to evaluating the costs and benefits of different climate change responses. While some types of responses emerge as preferable in terms of cost benefit ratios, the benefits need to be well-understood against the backdrop of the costs if decision-makers are to take investment decisions that will set the Western Cape on a positive path towards a climate resilient economy and population.

5 CONCLUSIONS

The CGE modelling produced ten simulations of the potential future state of the Western Cape economy by 2040, each using a unique set of assumptions regarding the level of climate change impact experienced in the Western Cape, the level of adaptation response of the WCG, and the level of adaptation response in the other provinces. The model findings reveal that there are significant economic and social risks associated with climate change in the Western Cape, and that there are significant economic and social advantages associated with investing in climate adaptation. Furthermore, it is evident that the climate adaptation responses of the other provinces will have a considerable influence on the economic future of the Western Cape, primarily from changes in intra-regional and international trade, and worker migrations between provinces.

To a certain extent, the benefits to the Western Cape that could emerge from climate change are a function of how much better than other provinces the Western Cape's adaptation response is. Effective adaptation can secure investment, an effective workforce, and impart new economic competitiveness.

A critical aspect that emerged was the impact that climate adaptation investment will have on households, confirming the link between social well-being and economic growth and / or stability in the province. A declining economy because of climate change impacts and a failure of the WCG to respond appropriately could have major impacts on consumer prices and the cost of living. The real estate services, agriculture, water, energy and transport sectors emerged as critical for climate resilient investment that protects social well-being by stabilising prices of major household consumption items.

Early, adequate, and well-directed investment in climate change adaptation can therefore be defined as a pro-poor approach. Such an approach would aim to ensure that the most vulnerable households are protected not only from increasing climate-related risks and resource scarcities, but also from escalating cost of living and economic decline that would result from a failure to invest adequately in climate change adaptation.

A CBA has been conducted on 16 climate change responses that government in the Western Cape is either in process of undertaking or plans to undertake. The CBA method has considered the cost of implementing these responses, as well as the benefits that are expected to arise from each. A Human Benefit Index, comprised of social, economic and ecological benefits in the context of climate change, was used as the measure of benefit that aligns with the mandate of provincial government in South Africa.

The CBA results have demonstrated that the different response options assessed have very different cost-benefit ratios. The installation of PV technology on government buildings emerged as the response with the best[20] cost-benefit ratio of the 16 options and is a response that saves money while reducing greenhouse emissions and creating work. Conservation agriculture and invasive alien plant clearing in the Berg/Breede River

[20] This result concurs with findings in Alberta, Canada, where a similar programme of PV installation on government buildings has been acclaimed.

Catchments emerged as the second and third best scoring options. These two projects scored well owing to their low investment cost (compared with other responses that are capital intensive) and high ability to create positive benefits for large numbers of people.

The more capital-intensive responses (such as BRT and desalination) scored lowest in the CBA. While these scored poorly in the CBA, it should be recognised that there are distinct nuances to evaluating the costs and benefits of different climate change responses. While some types of responses emerge as preferable in terms of cost benefit ratios, the benefits need to be well-understood against the backdrop of the costs if decision-makers are to take investment decisions that will set the Western Cape on a positive path towards a climate resilient economy and population.

During the selection of climate change responses to be analysed in the CBA, it was evident that cost-effective climate change responses can be found across a range of sectors and departments, highlighting that reducing climate change risks is a province-wide responsibility and not the domain of a single department or unit within the WCG.

Whilst the 16 climate change responses analysed in this study do not constitute a climate change response strategy, they do reveal that the WCG has planned, or is already busy with, activities that are economically valuable in terms of reducing climate change risk. It also assists in demonstrating how this value manifests through developmental, institutional and ecological pathways, and in identifying and prioritising climate change responses that turn the economic burden of climate change into an opportunity.

Through this study the WCG has provided local evidence of an emerging global narrative, regarding the links between economic activity and climate change, the default economic cost of climate change on specific sectors and the potential for climate resilient economies to gain competitive advantages and secure new growth opportunities. The compelling idea that climate change could provide the catalyst to positive economic and development outcomes is unlikely to emerge without considerable new investment and effort, much of which will have to be state-led. On the contrary, the default in which climate change imposes a net economic burden on the Western Cape economy remains most likely given the existing scale and nature of climate responses in the province. To avoid this default will require new and many more projects and programmes. This study provides important insights into the nature of the impact and the principles for an effective response should the WCG decide to avoid the risks, realise the opportunities and demonstrate regional leadership in the global response to anthropogenic climate change.

6 REFERENCES AND BIBLIOGRAPHY

Abidoyea, B.O. and Odusolab, A.F., 2015. Climate Change and Economic Growth in Africa: An Econometric Analysis. *Journal of African Economies*, pp 277–301, doi:10.1093/jae/eju033.

Blignaut, J.N., Ueckermann, L. and Aronson, J., 2009. Agriculture production's sensitivity to changes in climate in South Africa. *South African Journal of Science*, Vol 105, pp 61-68.

Borain, A., 2012. *Building effective partnerships for inclusive growth: Introduction to the Western Cape Economic Development Partnership (EDP).* Online: https://www.westerncape.gov.za/text/2012/7/economic-development-partnership-andrew-boraine.pdf

Cartwright, A., Blignaut, J.N., De Wit, M., Goldberg, K., Mander, M., O'Donoghue, S. and Roberts, D., 2013. Economics of climate change adaptation at the local scale under conditions of uncertainty and resource constraints: the case of Durban, South Africa. *Environment and Urbanization*, Vol 25(1), pp 139-156.

City of Cape Town, 2015. *Five-year Integrated Development Plan 2012-2017: 2015/16 Review and Amendments.* City of Cape Town, South Africa. Online: http://www.capetownpartnership.co.za/wp-content/uploads/2015/11/IDP-2015-2016-review.pdf

City of Cape Town, 2016. *Transit Oriented Strategic Development Framework*. Transit Oriented Development Technical Working Group, Cape Town, South Africa.

Colenbrander, S., Gouldson, A., Roy, J., Kerr, N., Sarkar, S., Hall, S., Sudmant, A., Ghatak, A., Chakravarty, D., Ganguly, D. and Mcanulla, F., 2016: Can low-carbon urban development be pro-poor? The case of Kolkata, India. *Http://Dx.Doi.Org/10.1177/0956247816677775*, 29, 139–158, doi:10.1177/0956247816677775.

Colenbrander, S., Sudmant, A.H., Gouldson, A., 2017. The Economics of Climate Mitigation: Exploring the Relative Significance of the Incentives for and Barriers to Low-carbon Investment in Urban Areas. *Urbanisation.* ISSN 2455-7471. doi.org/10.1177/2455747117708929

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W.J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver, A.J. and Wehner, M., 2013. Long-term climate change: Projections, commitments and irreversibility. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Doschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, Eds. Cambridge University Press, pp 1029-1136, doi:10.1017/CBO9781107415324.024.

Cote, M., and A. J. Nightingale, 2012: Resilience thinking meets social theory Situating social change in socio-ecological systems (SES) research. *Prog. Hum. Geogr.*, 36, 475–489, doi:10.1177/0309132511425708.

http://phg.sagepub.com/content/36/4/475%5Cnhttp://phg.sagepub.com/content/36/4/475.full.pdf%5Cnhttp://phg.sagepub.com/content/36/4/475.short.

CSAG (Climate Systems Analysis Group), 2016. *South African Provincial Climate Narratives.*

CSAG (Climate Systems Analysis Group), 2014. *Background Report on Climate Science Input into Municipal Climate Adaptation Plans*.

Daron, J. D., K. Sutherland, C. Jack, and B. C. Hewitson, 2014: The role of regional climate projections in managing complex socio-ecological systems. *Reg. Environ. Chang.*, 1–12, doi:10.1007/s10113-014-0631-y.

DEA (Department of Environmental Affairs), 2013. *Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa: Summary for Policy-Makers*. Online: https://www.environment.gov.za/sites/default/files/docs/summary_policymakers_bookV3.pdf

Dietz, S., 2009. Discounting and uncertainty in integrated assessment: the Stern Review and its critics. Climate Change: Global Risks, Challenges and Decisions. IOP Conf. Series: *Earth and Environmental Science,* 6 (2009).

DRDLR (Department of Rural Development and Land Reform), 2013. *Climate Change Risk and Vulnerability Assessment for Rural Human Settlements.* South African National Department of Rural Development and Land Reform, Pretoria, South Africa.

DWS (Department of Water and Sanitation), 2014. *Support to the Continuation of the Water Reconciliation Strategy for the Western Cape Water Supply System: Status Report October 2014*. Directorate National Water Resource Planning, Pretoria, South Africa.

Geels, F. W., F. Kern, G. Fuchs, N. Hinderer, G. Kungl, J. Mylan, M. Neukirch, and S. Wassermann, 2016: The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990-2014). *Res. Policy*, 45, 896–913, doi:10.1016/j.respol.2016.01.015. http://dx.doi.org/10.1016/j.respol.2016.01.015.

Global Commission on the Economy and Climate (GCEC), 2014. *Better growth, better climate: The new climate economy report*. Online: http://newclimateeconomy.report/2016/wp-content/uploads/sites/2/2014/08/BetterGrowth-BetterClimate_NCE_Synthesis-Report_web.pdf

Haustein, K., Otto, F., Uhe, P., Allen, M., and Cullen, H., 2016. Fast-track extreme event attribution: How fast can we disentangle thermodynamic (forced) and dynamic (internal) contributions? *Geophysical Research Abstracts.* Vol. 18, EGU2016-14875, 2016. EGU General Assembly 2016.

Hallegatte, S; Vogt-Schilb, A, Bangalore,M and Rozenberg, J., 2017: *Unbreakable : Building the Resilience of the Poor in the Face of Natural Disasters*. World Bank Group, http://hdl.handle.net/10986/25335.

High-Level Commission on Carbon Prices, Report of the High-Level Commission on Carbon Prices.

Hillmand, J., 2013. Changing Climate for Carbon Taxes: Who's afraid of the WTO?. *Climate and Energy Paper Series 2013.* The German Marshall Fund of the United States, Washington DC.

IPCC (Intergovernmental Panel on Climate Change), 2014. *Climate Change 2014: Synthesis Report.* Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC (Intergovernmental Panel on Climate Change), 2013. *Climate Change 2013: the physical science basis*. Switzerland.

IPCC (Intergovernmental Panel on Climate Change). 2007. *IPCC Fourth Assessment Report: Climate Change 2007 – Synthesis Report.* Online: https://www.ipcc.ch/publications_and_data/ar4/syr/en/mains1.html

Kirtman, B., Power, S.B., Adedoyin, J.A., Boer, G.J., Bojariu, R., Camilloni, I., Doblas-Reyes, F.J., Fiore, A.M., Kimoto, M., Meehl, G.A., Prather, M. Sarr, A., Schär, C., Sutton, R., van Oldenborgh, G.J., Vecchi, G. and Wang, H.J., 2013. Near-term Climate Change: Projections and Predictability. In: *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Mather, A., Garland, D. and Stretch, D., 2009. Southern African sea-levels: corrections, influences and trends. *African Journal of Marine Science*, 31, pp. 145-156.

Midgley, G.F., Scholes, R.J. von Maltitz, G., Archer, E., Blignaut, J.N. 2011. *Scoping of the approximate climate change adaptation costs in several key sectors for South Africa up to 2050*. GIZ report, Report number SKMBT_C45010121508500.

NASA, 2017. "2016 warmest year on record globally, NASA and NOAA data show: Third record-breaking year in a row for average surface temperatures." *ScienceDaily*, 18 January 2017. Online: www.sciencedaily.com/releases/2017/01/170118112554.htm

National Treasury, 2016. *Draft Regulations: Carbon Offsets.* Online: http://www.treasury.gov.za/public%20comments/CarbonTaxBill2016/Carbon%20offset%20Regulations.pdf

National Treasury, 2015. *Draft Carbon Tax Bill.* Online: http://www.treasury.gov.za/public%20comments/CarbonTaxBill2015/Carbon%20Tax%20Bill%20final%20for%20release%20for%20comment.pdf

National Treasury 2013. *Carbon Tax Policy Paper.* Online: http://www.treasury.gov.za/public%20comments/Carbon%20Tax%20Policy%20Paper%202013.pdf

New, M. and Hulme, M., 2000. Representing uncertainty in climate change scenarios: a Monte–Carlo approach. *Integrated Assessment* 1, pp 203–213. doi:10.1023/A:1019144202120.

Nordhaus, W.D., 2013. *The Climate Casino. Risk, Uncertainty and Economics for a Warming World.* Yale University Press.

Nordhaus, W.D., 2001. Global Warming Economics. *Science*, Vol 294. Online: http://www.kleykampintaiwan.com/files/GradEco/nordhaus.pdf

OECD (Organization for Economic Cooperation and Development), 2017. *Investing in Climate, Investing in Growth.* Paris, France: OECD Publishing, Paris, France doi:10.1787/9789264273528-1-en.

OECD (Organization for Economic Cooperation and Development), 2011. *Towards Green Growth: a Summary for Policy Makers.* Online: http://www.oecd.org/greengrowth/48012345.pdf

Otto, F.E., Frame, D.J., Otto, A. and Allen, M.R., 2015. Embracing uncertainty in climate change policy. *Nature Climate Change,* Vol 5. Pp 917-920. Doi:10.1038/nclimate2716

Pelling, M., H. Leck, L. Pasquini, I. Ajibade, E. Osuteye, S. Parbnell, and S. Lwasa, (under review). Africa's Urban Adaptation Transition Under a 1.5 Degree. *Curr. Opin. Environ. Sustain.*

Pfeiffer, M., Stepanek, C., Lohmann, G., 2016. Simulated global annual mean precipitation for Pre-Industrial and for 8 ka BP, link to model results in NetCDF format. *PANGAEA*, https://doi.org/10.1594/PANGAEA.870989

Rode, P., C. Heeckt, R. Ahrend, O. H. Melchor, A. Robert, N. Badstuber, A. Hoolachan, and C. Kwami, Integrating national policies to deliver compact , connected cities : an overview of transport and housing. 1–88.

Rozenberg, J. and Hallegatte, S., 2015. *The Impacts of Climate Change on Poverty in 2030 and the Potential from Rapid, Inclusive, and Climate-Informed Development.* doi:10.1596/1813-9450-7483. Online: https://openknowledge.worldbank.org/handle/10986/23447

Safarzyńska, K., and van den Bergh, J. C. J. M., 2017. Financial stability at risk due to investing rapidly in renewable energy. *Energy Policy* 108, 12–20. doi:10.1016/j.enpol.2017.05.042.

Seto, K. C., Davis, S.J., Mitchell, R.B., Stokes, E.C., Unruh, G. and Ürge-Vorsatz, D., 2016. Carbon Lock-In: Types, 5 Causes, and Policy Implications. *Annual Review of Environmental Resources*, Vol 41, pp 425–452.

Standard and Poor's, 2016. *The Paris Agreement: a new dawn for tackling climate change or more of the same.* Online: https://www.ipfa.org/wpcontent/uploads/2016/01/View-the-full-report.pdf

Stern, N., 2016. Current climate models are grossly misleading: Nicholas Stern calls on scientists, engineers and economists to help policymakers by better modelling the immense risks to future generations, and the potential for action. *Nature*. Online: http://go.galegroup.com/ps/anonymous?id=GALE%7CA444595364&sid=googleScholar&v=2.1&it=r&linkaccess=fulltext&issn=00280836&p=AONE&sw=w&authCount=1&isAnonymousEntry=true

Stern, N. (2015). Economic development, climate and values: making policy. *Proceedings of the Royal Society of London B: Biological Sciences* 282, n/a-n/a.

Stern, N. (2013). The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models. *Journal of Economic Literature* 51, 838–859. doi:10.1257/jel.51.3.838.

Stern, N., 2006. *The Economics of Climate Change: The Stern Review*. Cambridge University Press. United Kingdom. doi.org/10.1017/CBO9780511817434

Stiglitz, J.E. and Stern, N., 2017. *Report of the High-Level Commission on Carbon Prices.* Carbon Pricing Leadership Coalition and The World Bank. Online: https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59244eed17bffc0ac256cf16/1495551740633/CarbonPricing_Final_May29.pdf

Taylor, A., Cartwright, A. and Sutherland, C., 2014. Institutional Pathways for Local Climate Adaptation: A Comparison of Three South African Municipalities. *Focales,* Vol 18. AFD. Online: http://recherche.afd.fr

Tol, R.S.J., 2009. The economic effects of climate change. *Journal of Economic Perspectives*, Vol 23(2), pp 29-51.

Turpie, J. and Visser. M., 2014. *The impact of climate change on South Africa's rural areas*. Chapter 4 to the submission for the 2013/14 Division of Revenue. Online: http://www.ffc.co.za/docman-menu-item/commission-submissions/300-chapter-4-impact-of-climate-change-on-south-africas-rural-areas2

UNDP (United Nations Development Programme, 2016. *Scaling up Climate Action to Achieve the Sustainable Development Goals.* Online: file:///C:/Users/Nicci/Downloads/Climate%20Change%20and%20the%20SDGs%20English%20Report.pdf

UNDP (United Nations Development Programme), 2010. *Mapping Climate Change Vulnerability and Climate Scenarios: A handbook for sub-national planners*. Online: http://europeandcis.undp.org/uploads/public1/files/Mapping%20CC%20Vulnerability%20publication%20-%20November%202010.pdf.

UNEP (United Nations Environment Programme), 2016. *The Adaptation Finance Gap Report 2016.* United Nations Environment Programme (UNEP), Nairobi, Kenya. Online: http://www.unep.org/climatechange/adaptation/gapreport2016/

UNEP (United Nations Environment Programme), 2011. *Decoupling natural resource use and environmental impacts from economic growth.* A Report of the Working Group on Decoupling to the International Resource Panel.

Van Heerden, J., Blignaut, J., Bohlmann, H., Cartwright., A., Diederichs, N. and Mander, M., 2016. The economic and environmental effects of a carbon tax in South Africa: A dynamic CGE modelling approach. *South African Journal of Economic and Management Sciences,* Vol 19(5), pp 714-732.

WCG (Western Cape Government), 2016a. *SmartAgri: Western Cape Climate Change Response Framework and Implementation Plan for the Agriculture Sector.* Department of Agriculture and Department of Environmental Affairs and Development Planning, Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2016b. *SmartAgri: A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape province.* Department of Agriculture and Department of Environmental Affairs and Development Planning, Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2016c. *WC Energy Consumption and CO2 Emissions Database.* Department of Environmental Affairs and Development Planning.

WCG (Western Cape Government), 2015. *Western Cape Climate Change Mitigation Scenarios for the Energy Sector*. Department of Environmental Affairs and Development Planning, Cape Town.

WCG (Western Cape Government), 2014a. *Provincial Strategic Plan 2014-2019.* Office of the Premier, Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2014b. *Western Cape Climate Change Response Strategy.* Department of Environmental Affairs and Development Planning, Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2013a. *Green is Smart: Western Cape Green Economy Strategy Framework.* Department of Environmental Affairs and Development Planning, Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2013b. *Energy Consumption and CO2e Emissions Database for the Western Cape province*. Department of Environmental Affairs and Development Planning, Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2013c. *Western Cape Infrastructure Framework*. Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2012a. *Western Cape Sustainable Water Management Plan*. Department of Environmental Affairs and Development Planning, Western Cape Government. Cape Town, South Africa.

WCG (Western Cape Government), 2012b. *OneCape2040: From Vision to Action.* Office of the Premier, Western Cape Government. Cape Town, South Africa.

ANNEXURE 1 – EXPERT INPUTS TO THE STUDY

Given that the economics of climate change is an emerging area of study, and there remains much uncertainty about how climate change will affect the Western Cape Province's economy, and how different sectors may reasonably adapt these impacts, the study has been deliberately consultative to facilitate the incorporation of expert opinion wherever possible.

A **Project Steering Committee (PSC)** chaired by the Western Cape Department of Environmental Affairs and Development Planning (DEA&DP) has been set up to direct the study process and review the outcomes. The PSC includes representation from:

- City of Cape Town (the only Metropolitan Municipality in the province);
- Western Cape Department of Agriculture (DOA); and
- Western Cape Department of Economic Development and Tourism (DEDAT);

A series of Expert Working Groups, comprising a broad spectrum of Western Cape sectoral experts from government, research organisations and the private sector, were also convened. The purpose of these Expert Working Groups is to provide expert input into key components of the study process, including:

- Input into the development of the narratives and assumptions associated with each scenario that was used in the CGE modelling process;
- Review of the CGE modelling outcomes and input into any modelling refinements that needed to be undertaken;
- Input into the identification of priority climate adaptation / resilience investments or responses that are to be assessed in the CBA process;
- Input into the identification of costs and benefits associated with each priority adaptation / resilience investment studied in the CBA process.

The Expert Working Groups, which met several times throughout the study process, comprised the following:

- **Agricultural Technical Expert Committee**, with representation / participation from DOA, DEA&DP, GreenCape, University of Cape Town's Climate Systems Analysis Group;

- **Energy Technical Expert Committee,** with representation / participation from the DEDAT, DEA&DP, GreenCape, The Green House and PDG.

- **Transport and Construction Technical Expert Committee**, with representation / participation from Western Cape Department of Transport and Public Works, DEA&DP, GreenCape and PDG.

- **Water Technical Expert Committee,** with representation / participation from DEA&DP, DEDAT, GreenCape, PDG and Aurecon.

ANNEXURE 2 – CBA CLIMATE CHANGE RESPONSES AND ASSUMPTIONS

In conducting a climate change CBA, it is critical that people performing the analysis share the same understanding of the project, programme or institutional response that is being evaluated. This annex provides the details, and modelling assumptions, of the 16 climate change responses that were evaluated in this study.

Conservation Agriculture:

Conservation agriculture (CA) describes farming practices that combine minimum soil disturbance, maximum soil cover, and crop rotation/mixing. In South Africa, CA is most commonly associated with wheat, maize and other cereals. In the last few years the Western Cape Department of Agriculture has been active in researching and promoting CA amongst farmers (and is extending CA to other crops). In a survey of wheat farmers, 84% indicated that adoption of CA had been good for yields, and 94% reported higher profits (due to reduced farming costs and better yields). The adoption of CA is particularly useful in providing resilience during times of droughts, which are expected to increase in intensity and frequency in the region. In the analysis it was assumed that CA in the Western Cape Province would impact on 80% of the provincial population by reducing food price inflation. CA on its own does not save any lives. Factoring in climate change impacts over a 25-year period, this model assumes that CA will have a "significant improvement" on 5% of the population, impacted through the protection of agricultural jobs and access to affordable food, a moderate improvement on 20% of the population, and a slight/ weak improvement on 75% of the population. The latter two categories impacted through food prices. CA can sequestrate atmospheric carbon, improve food security and protect agricultural employment.

For the purposes of this study it was assumed that CA required R40 million capital expenditure from the public sector, spread equally over 5 years and a further R4 million per annum in operating expenditure by way of research and awareness raising over the 25-year lifetime of the project. In terms of intrinsic merit as a climate change response, provincial government officials scored CA 2.82 out of 5, using the weighted multi-criteria assessment.

Fruitlook:

Fruitlook is a 'precision farming' support programme that is supported by the Western Cape Department of Agriculture in a three-year programme. The Department spends R1 million in capital expenditure, spread over the three years, and R9 million every year in operating expenditure. The programme enables more accurate crop water and fertiliser applications, resulting in less water use and better yields. It is assumed that Fruitlook impacts upon 10% of the provincial population through employment and improved water availability. Government's support for Fruitlook holds the potential to save 0.5% of the population's lives through water availability over the 25-year period of analysis. Fruitlook is assumed to have a "significant positive" effect on a further 25% of the population," moderate positive effect" on 40%, and a weak positive effect on 34.5% of the population. In terms of intrinsic merit as a climate change response, provincial government officials scored Fruitlook 2.62 out of 5, using the weighted multi-criteria assessment.

Landcare:

Landcare is a community works programme funded by national government and managed by provincial government. The programme aims to counter the impact of erosion and soil degradation. Teams of people working for the Landcare programme rehabilitate dongas, badlands and gullies that would otherwise lead to accelerated erosion, loss of topsoil and dam siltation. The WCG spends R23 million operating expenditure every year on this programme. Some soil carbon is sequestered and jobs are created. Landcare does not save lives directly and only impacts on 7.5% of the provincial population in some way. The programme does have a significant positive impact on 25% of population that is impacted, a moderate effect on 40% of this population and a small positive effect on 35% of the impacted population. In terms of intrinsic merit, as a climate response, provincial government officials scored this option 3.00 out of 5, using the weighted multi-criteria assessment.

Agricultural Disaster Relief:

Agriculture disaster relief is provided from the national and provincial fiscus once a natural disaster has been declared for the agricultural sector in a particular region. Historically crop and livestock losses caused by drought, flood and hail have been the reasons for mobilising the disaster relief and management. The programme costs government R75 million per annum in operating expenditure and is expected to become increasingly important, and an annual requirement, as climate change impacts are amplified. Over a 25-year lifespan, disaster relief is expected to impact upon the lives of 80% of the provincial population in some way. In the analysis it is expected to save the lives of an estimated 0.5% of this part of the population, significantly improve the lives of 10.5% of the affected population and "moderately" and "slightly" improve the lives of 30% and 59% of the impacted population, respectively. In terms of intrinsic merit as a climate response, provincial government officials scored this option 1.52 out of 5, using the weighted multi-criteria assessment. The lower rating results because it is a reactive measure with discreet emergency response, rather than a long term proactive climate response.

The Upgrading of Informal Settlements Programme (UISP):

The programme run by the Western Cape Department of Human Settlements and works with informal settlement dwellers to map the lay-out of housing units, use more resilient building material and provide basic services such as water, sanitation and energy. The UISP is considered important in providing household-scale resilience to cope with various climate change related stresses. The programme has the potential to reach the 20% of people in the Western Cape Province that live in informal settlements, saving the lives of 0.1% of these people, significantly improving the lives of 44.9%, and moderately improving the lives of 30%. It is expected to have a slight/ weak positive impact on 25% of the informal population. The programme costs the state R388 million per annum and will run for the full 25 years under consideration in this analysis. In terms of intrinsic merit as a climate response, provincial government officials scored this option 3.2 out of 5, using the weighted multi-criteria assessment.

Desalination - large scale:

Large scale desalination refers to a project that can generate over 100 million litres of water per day (10-20% of Cape Town's demands depending on the level of restriction). The project that is modelled in this study involves a hypothetical plant (or plants) capable of generating 220 million litres per day. The capital cost of this project would have to be shared between national, provincial and local government. For the purposes of the model it is assumed that a large-scale plant would cost R15 billion to construct and this would be spread over two years. The operating cost of this large-scale plant is assumed to be R1,314 billion per annum. The population reach of this scale of desalination project is based on a per capita consumption assumption of 87 litres per day (Level 5 water restrictions), and so estimated at 38.8% of the provincial population (2.5 million people). Over a 25-year time horizon, once climate impacts are factored in, a large desalination plant of this nature is expected to save the lives of 0.5% of the 2.5 million affected population, but to "significantly improve", the balance of the impacted population (99.5%). Applying the weighted multi-criteria evaluation, provincial government officials scored large-scale desalination 2.04 out of a possible 5 in terms of intrinsic merit as a climate response. This measure of intrinsic merit is independent of scale and cost.

Desalination – small-scale:

The modelling of small-scale desalination in this study is based on the commissioned project at Harmony Park. This project is expected to generate 8 million litres of water per day. Capital costs are borne by the contractor, but the City of Cape Town is obliged to purchase the generated water at a prescribed price and rate and has a bilateral agreement with the contractor regarding electricity. The cost per cubic metre of water generated is estimated at R91, and the total annual cost of procuring water from this plant is R73 million. The scale of the Harmony plant means that it can only provide water for 1.6% of the provincial population. It saves the lives of 0.5% of the affected people, significantly improves the lives of 50% of these people and imparts moderate benefits on 49.5% of the impacted people. In terms of the weighted multi-criteria evaluation of the intrinsic merits of desalination plants as a climate change response conducted by provincial government officials, small-scale desalination scores 2.04 out of a possible 5. This measure of intrinsic adaptation merit is independent of scale and cost.

PV on government buildings:

The WCG runs an energy efficiency programme aimed at reducing demand for electricity from public sector buildings by 30% over 3 years. As part of this programme, the Department of Public Works installs smart meters and photovoltaic (PV) technologies on buildings owned or occupied by WCG departments to reduce greenhouse gas emissions and reduce the money paid to Eskom (via the local municipality in some instances) for electricity. Testimony to this programme is the growing number of government buildings awarded a 5-star rating by the Green Building Council of South Africa (see Khayelitsha and Bellville). The falling cost of photovoltaic electricity results in these installations saving the WCG money over time.

The programme has a capital cost of R1,2 billion, spent over 5 years, but thereafter saves R80 million per annum in operating expenditure (electricity). It only impacts on 5% of the province's population. The installation of PV itself does not save any lives, and in general the impacts arising from this project on people's lives are loaded towards the "moderate" (20%) and "slight/ weak" (75%) end of the impact spectrum. These impacts arise from more cost-effective government services. In terms of the weighted multi-criteria evaluation of the intrinsic merits of PV installed on government buildings, as a climate change response, this option was scored at 1.9 out of a possible 5. This measure of intrinsic adaptation merit is independent of scale and cost.

Water Re-use:

The WCG and the City of Cape Town are implementing a water re-use project that uses reverse osmosis technology to augment the supply of potable water. This programme aims to generate 50 million litres of water a day, thereby suppling 9.7% of the provincial population with 87 litres of water per person per day. The programme relies on private contractors but involves a guaranteed off-take of water that covers operating costs. This will cost the public sector R182.5 million per annum. As with large-scale desalination, the project saves the lives of 0.5% of the 10% of the provincial population that it benefits, and significantly improves the lives of the balance (99.5%) of those people due to reduced risk of running out of water.

In terms of the multi-criteria evaluation of the intrinsic merits of water re-use as a climate change response, this option scored 2.16 out of a possible 5.

Atlantis SEZ:

The existing Special Economic Zone (SEZ) near the dormitory town of Atlantis has attracted green economy businesses and created agglomeration effects through the provision of green energy and reduced tariffs and rentals. The creation of an SEZ required investments by the provincial and national government. To date the WCG has invested R250 million in infrastructure to establish the site (and is awaiting investment from the Department of Trade and Industry). The expense covered rooftop PV and water upgrades and was allocated over two years. The SEZ now has 1,200 employees and 17 active companies most of which are active in the green economy e.g. PV panel manufacturing, smart metres and wind turbine manufacturing. These companies paid an estimated R8 million in taxes to the national government in 2015.

The project impacts upon the lives of 5% of the provincial population, predominantly through work creation and in assisting the transition to a green economy. It does not save lives and 75% of those impacted receive only a "weak/ slight" improvement in their welfare. In terms of the weighted multi-criteria score for intrinsic merit as a climate response, the Atlantis SEZ was scored at 2.4 out of 5 by WCG officials.

Waste-recycling depot:

The City of Cape Town has costed and scoped the roll-out of waste diversion sites run by community-based co-operatives that sort, recycle and upcycle waste in municipal waste streams. These sites reduce the chronic burden of waste in landfills, create employment and save greenhouse gas emissions. The City of Cape Town has used its Hout Bay Recycling Co-operative (HBRC) as a precedent in planning an extension of this mode of waste handling while creating work, alleviating the problem of landfills and expensive waste dumping. The HBRC model is scalable across the Western Cape Province, but to replicate it at one additional site would cost the city a R1.6 million once-off capital investment and R400,000 per annum in operating expenses.

The project could improve the lives of 2% of the provincial population through waste to landfill, reduced storm-water drain blockages, reduced water contamination and the saving of greenhouse gas emissions. The project would create permanent employment for 15 people and work for over 100 waste pickers in an informal settlement. In terms of intrinsic merit as a climate response, WCG officials scored this option 2.7 out of 5 in the weighted multi-criteria assessment.

BRT Phase 1:

The first phase of the City of Cape Town's Bus Rapid Transit (BRT) system, links the Atlantis Corridor and Inner City. The phase cost R4 billion on capital expenditure over 5 years and continues to cost R200 million in operating expenditure deficit every year. This phase of the BRT impacts upon 1,3 million people in the province through reduced commuting time and lower costs, reduced congestion and road accidents and less particulate pollution in and around the city. The BRT also reduced greenhouse gas emissions relative to private cars.

Of the 1,3 million people impacted by the BRT, only 0.1% have their lives saved by the response, 25% have their lives significantly improved, 30% have their lives moderately improved and 50% experience only weak improvements in their well-being. In terms of intrinsic merit as a climate response, WCG officials scored this option 1.9 out of 5 using the weighted multi-criteria assessment.

Artificial wetland to remediate industrial effluent:

Construction and maintenance of a wetland to assist in the remediation of industrial effluent from Mbekweni before it enters the Berg River outside Paarl, forms part of the Berg River Improvement Programme and has proven its ability to complement the struggling waste-water treatments plants in that catchment. The project will create work, ecosystem restoration and management, and will impact on 1.5% of the provincial population through improved quality of water in the Berg River. It does not save lives, but significantly improves the lives of 25% of the affected population working on downstream farms and living in adjacent communities. The wetlands are built and maintained using local vegetation and local labour and will create work for 300 people. The public cost of the project was estimated at R4 million, spent over three years and a further R1 million every year in operating expenses (mostly labour). In terms of intrinsic merit as a climate response, WCG officials scored this option 3.24 out of 5 using the weighted multi-criteria assessment.

Clearing alien invasive species from water catchments:

The Western Cape Province is home to Public Works programmes that remove invasive alien tree species from water catchments to enhance the supply of water to rivers and dams. The existing programmes operate in the Upper Berg and the Upper Breede River Catchments, and impact on an estimated 40% of the provincial population via enhanced water availability. Research by David Le Maître, and others, shows that this is the most cost-effective way of increasing water supplies to the Western Cape Province.

The programme receives capital expenditure of R5 million which it has spent over 5 years, and operating expenditure of R5 million per annum. In terms of intrinsic merit as a climate response, WCG officials scored this option 3.12 out of 5 using the weighted multi-criteria assessment, largely due to its labour intensity.

Installation of boreholes at critical sites:

Several employees in the Provincial Department of Transport and Public Works have formed part of a new workstream called "business continuity" aimed at retaining a supply of water to important sites. This workstream is ongoing but has installed boreholes and well-points at schools and hospitals in particular.

The programme is estimated to cost R300 million in capital expenditure over 3 years and an additional R30 million per year in operating expenditure (electricity, monitoring and maintenance). It is expected to impact on 10% of the provincial population but will only save the lives of 0.5% of that 10% over a 25-year period. The rest of the impact will be split between "significant" and moderate" improvement. In terms of intrinsic merit as a climate response, WCG officials scored this option 2.24 out of 5 using the weighted multi-criteria assessment.

GreenCape:

GreenCape is a Western Cape special purpose vehicle aimed at generating new knowledge and business support capacity that positions the Western Cape as a global leader in the green economy. It is difficult to attribute investment that arrives in the Western Cape to GreenCape exclusively, as confounding influences exist, but the award-winning institution has undoubtedly succeeded in growing the province's green economy and making investment in this economy easier. Specific success has involved securing the South African Renewable Energy Technology Centre in the province, in securing the bulk of REIPPP investment, in attracting investment to the SEZ and in running the Western Cape Industrial Symbiosis Programme (WISP). GreenCape receives money from various sources but costs the fiscus R26.4 million per year. GreenCape does not require capital expenditure.

GreenCape's existence makes a difference to an estimated 10% of the Province's population, but most of this impact is indirect. In the context of climate change, only 2% of that 10% will have their lives 'saved' by GreenCape over the next 25 years, whereas 50% of the impacted 10% will experience a significant improvement and 25% will experience a moderate improvement. In terms of intrinsic merit as a climate response, WCG officials scored this option highest at 3.52 out of 5, using the weighted multi-criteria assessment.

Other project and programmes not included in the analysis:

The Western Cape Province is home to several innovative green economy and climate change response projects. Examples include the R400 million New Horizon biodigester and the securing of an LNG hub at Ankerlig that could provide an energy feedstock to the country. These initiatives are privately funded and managed and seek to supply services and goods to private companies. For this reason, they are not easily comparable with public sector services aimed at generating the public goods that this study seeks to analyse in the context of climate change.

Similarly, the Energy Game Changer programme run by the WCG aims to reduce provincial demand for electricity by 10% by 2020 and appears to have many favourable attributes. However, cost data on this project was not forthcoming for to this study, and it was therefore excluded.

ANNEXURE 3 - DEFINING CLIMATE CHANGE APPROACHES AND CONCEPTS

There are several concepts and approaches that are commonly used in the context of climate change reports, these are defined as follows:

Climate Change:

The National Climate Change Response White Paper (DEA, 2011) defines climate change as "… an ongoing trend of changes in the earth's general weather conditions as a result of an average rise in the temperature of the earth's surface often referred to as global warming. This rise in the average global temperature is due, primarily, to the increased concentration of greenhouse gases in the atmosphere that are emitted by human activities. These gases intensify a natural phenomenon called the "greenhouse effect" by forming an insulating layer in the atmosphere that reduces the amount of the sun's heat that radiates back into space and therefore has the effect of making the earth warmer."

The Intergovernmental Panel on Climate Change (IPCC) (2007) defines climate change as: "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and / or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity."

The UNFCCC definition differs: "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (IPCC, 2007).

The Food and Agriculture Organisation (2007) defines it as: "Any change in climate over time, whether due to natural variability or anthropogenic forces".

Climate Variability:

Variations in the mean state of the given climate for a specific region over time (FAO, 2007).

The IPCC (2007) defines climate variability as: variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Climate Change Adaptation:

According to The Victorian Centre for Climate Change Adaptation Research (2017):

- the UNFCCC defines climate change adaptation as actions taken to help communities and ecosystems cope with changing climate condition;

- the IPCC describes it as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities;
- the United Nations Development Program (UNDP) calls it a process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed, and implemented;
- the United Kingdom Climate Impacts Program defines it as the process or outcome of a process that leads to a reduction in harm or risk of harm, or realisation of benefits associated with climate variability and climate change.

The National Climate Change Response White Paper (DEA, 2011) states that: "Responses to climate change have been commonly categorised as either aimed at reducing the rate at which climate is changing to levels that occur naturally (and especially reducing the atmospheric concentrations of GHGs, so-called "mitigation") or responding to the adverse effects of climate change ("adaptation")."

The IPCC (2007) defines **Adaptive Capacity** (to climate change) as: the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Climate Change Mitigation:

According to the United Nations Environment Programme (UNEP) (2017), climate mitigation refers to efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behaviour.

According to the IPCC (2007), climate mitigation is an anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

Natural Hazards:

Natural processes or phenomena, such as extreme climatological, hydrological or geological processes, that may constitute a damaging event. Hazardous events can vary in magnitude or intensity, frequency, duration, area of extent, speed of onset, spatial dispersion and temporal spacing (WCG, 2010).

Resilience:

The capacity of a system, community or society potentially exposed to hazards to adapt by resisting or changing to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve disaster risk reduction measures (WCG, 2010).

Risk (disaster risk):

The probability of harmful consequences or expected losses (deaths, injuries, property, livelihoods, disrupted economic activity or environmental damage) resulting from interactions between natural or human-induced hazards and vulnerable conditions. Conventionally risk is expressed as follows:

$$Risk = Hazard\ X\ Vulnerability$$

Some disciplines also include the concept of exposure to refer particularly to the physical aspects of vulnerability (WCG, 2010).

Sensitivity (to climate change):

According to the IPCC, Sensitivity is the degree to which a system will respond to a change in climatic conditions (e.g., the extent of change in ecosystem composition, structure, and functioning, including primary productivity, resulting from a given change in temperature or precipitation).

Vulnerability (to climate change):

$$Vulnerability = \frac{Exposure\ to\ climate\ hazards\ and\ perturbations\ X\ Sensitivity}{Adaptive\ capacity}$$

(UNDP, 2010)

Vulnerability is a result of a combination between the environmental risks that society's face and their abilities to cope with those risks (DRDLR, 2013).

The degree to which an individual, a household, a community, an area or a development may be adversely affected by the impact of a (climate related) hazard. Conditions of vulnerability and susceptibility to the impact of (climate related) hazards are determined by physical, social, economic and environmental factors or processes (WCG, 2010).

According to the IPCC, vulnerability defines the extent to which climate change may damage or harm a system. It depends not only on a system's sensitivity but also on its ability to adapt to new climatic conditions.

Department of Environmental Affairs and Development Planning
Leeusig Building, 4th Floor, 1 Dorp Street, Cape Town, 8001
Private Bag X9086, Cape Town, 8000
Telephone: +27 (0)21 483 5126
Email:

Western Cape Government
Environmental Affairs and Development Planning

BETTER TOGETHER.