South African Benchmark Climate Risk Scenarios

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1. Introduction and background

1.1. Climate change is a systemic risk to the financial sector that warrants heightened scrutiny and mitigation efforts of regulators. Bolton et al. (2020) argue that climate change will generate highly disruptive events resulting in environmental, social, and economic impacts that will be felt primarily through the financial system. Financial and non-financial firms are likely to experience significant stress due to climate change (Carney, 2015). Huxham et al. (2019) highlight the transition risks associated with a low carbon transition in South Africa and estimate that financial losses of over USD120 billion between the period 2013 and 2035 could be realised[1].

1.2. A study undertaken jointly with the South African National Treasury (NT) and the United Nations University (Cullis et al., 2015) also confirmed that there is a high probability of significant climate change impacts to the economy of South Africa and thus related social and financial impacts. Climate change impacts are expectedly experienced from the 2020s with the severity of these increasing with time. These include enhanced frequency and severity of extreme events.

1.3. In response to climate-related risks faced by the domestic financial sector, National Treasury published the Technical Paper on "Financing a Sustainable Economy"[2] in May 2020, updated in August 2021, as a framework for financial institutions to better disclose public information on their green practices and investments, and to stimulate the allocation of capital to support a development-focused and climate-resilient economy. One of the recommendations of the paper is to "Develop a benchmark climate risk scenario for use in stress tests by the sector". A Steering Committee and Working Groups were established to support the implementation of the Technical Paper recommendations. These include a Benchmark Scenario Working Group chaired by the Prudential Authority and including representatives from National Treasury, the South African Reserve Bank, and the Financial Sector Conduct Authority (FSCA). The initial phase of work for the Working Group is supported by the International Food Policy and Research Institute (IFPRI).

1.4. This paper is a product of the Working Group and aims to document an approach to developing climate-related scenarios and present the first set of these scenarios, which cover transition and physical risks. Climate-related risk scenarios are in early stages of development, and require considerable data, skills and expertise. The benchmark scenarios presented in this report leverage domestic work done and align these South African models and scenarios with international developments. The objective in publishing these scenarios is to enable information sharing and knowledge building in an open and transparent manner. The development of these benchmark scenarios is primarily for financial firms to improve their understanding of risks and capabilities, and not

[1] The value presents the present value of losses for the period.
[2] The paper is available at https://sustainablefinanceinitiative.org.za/

for policy or supervisory objectives. Scenarios, by their nature, can often provide more questions than answers, and thus require an iterative process.

1.5. The Network for Greening the Financial System (NGFS) was formed 'to exchange experiences, share best practices, contribute to the development of environment and climate risk management in the financial sector, and to mobilize mainstream finance to support the transition toward a sustainable economy'. Since its establishment in 2017, the NGFS has grown in prominence and extended itself to many emerging market economies such as South Africa. The South African Reserve Bank (SARB) became a member of the NGFS in 2019 and participates in the various working groups.

1.6. This programme of work is also intended to contribute towards the work of the NGFS and mapping of NGFS scenarios to the South African case. We illustrate that previously modelled scenarios (developed and run without any reference to NGFS) map acceptably to a subset of NGFS scenarios. Like NGFS scenarios, the scenarios described in this paper do not provide an analysis of the impact on the financial sector as it is deemed the responsibility of each financial institution to generate these impacts.

1.7. In addition to the NGFS, there are various international guidelines and frameworks to address climate-related risks which cover scenario analysis, particularly as they relate to disclosures. The Taskforce on Climate-related Financial Disclosures (TCFD) and the International Sustainability Standards Board (ISSB) are two noteworthy examples. Climate-related risk disclosures represent a new and evolving discipline for which there are globally disparate levels of technical expertise, methodological alignment, and data availability. Local material has been developed[3] which provide practical guidance and inform a common dialogue and domestic efforts to ensure the safety and soundness of the South African financial sector and provide decision-useful information to market participants and stakeholders more broadly. This report and these scenarios intend to contribute to this body of knowledge, under the South African Sustainable Finance Initiative. The reporting and disclosure of scenarios is not covered in this report.

Scenario analysis and stress testing

1.8. The objective of climate scenario analysis is for policymakers, regulators and companies to better understand the potential impacts of climate change on the financial sector using a forward-looking framework. The scenarios reflect potential future states of the world because of climate change and the corresponding impacts to banks, insurers and financial corporates.

[3] Such as South Africa's Sustainable Finance Initiative Principles for Disclosure, JSE Sustainability and Climate Change Disclosure Guidelines and the project entitled Aligning South Africa's climate-related financial disclosure with global best practice, led by DNA Economics.

1.9. This process will include the development of comprehensive tools that will enable an understanding of transmission channels. Developing integrated assessment models and linking them to stress-testing models will take time. As a result, a phased approach will be utilised to implement the recommendations of the NGFS[4]. These include explicit modelling of physical and transition risks, geographical coverage and sector granularity that reflect South Africa's climate dynamics and exposure, and the incorporation of alternative policy developments and climate uncertainty.

1.10. What is key is specifying the scenarios and establishing their implications to ensure that climate-related risks (both physical and transition) are identified, measured, monitored, managed, and reported. The scenarios should describe the likely paths of climate change, indicating where global emissions have increased, stabilised, or decreased. It is certain that some combination of physical and transition risks will occur in future, while its exact consequences and timing remains unclear. The magnitude of the impact of climate-related risks will depend on actions taken by governments, institutions, and individuals. However, physical risks are likely to advance gradually as global emissions accumulate.

1.11. Scenario analysis is a key part of stress testing frameworks. According to the Basel Committee on Banking Supervision (BCBS, 2021), stress testing in the context of climate risk analysis is defined as "the evaluation of a financial institution's financial position under a severe but plausible scenario". The term "stress testing" is also used to refer to the mechanics of applying specific individual firm level tests and to the wider environment within which the tests are developed, evaluated, and used within the decision-making process. The objective of climate stress-testing is to establish how financial risks emanating from climate risks will impact financial institutions under stressed circumstances. Based on the outcome of the stress tests, institutions can then assess the financial resources needed and respond and establish remedial actions enabling them to better respond to climate-related and other risks.

1.12. The SARB Financial Stability Unit undertakes stress tests on systemically important financial institutions to assess the solvency and liquidity profile of the SA banking sector. The results are used internally by the SARB and are sector-wide results are published in the SARB Financial Stability Review. The stress tests have no impact on the prudential regulatory capital requirements. The SARB stress test has a macro prudential focus and international comparability is a key consideration. The SARB stress testing is one of the macroprudential monitoring tools used to assess financial stability and resilience. These benchmark scenarios developed have a micro- prudential focus, and are intended as a tool for all banks, insurers, and other firms to use as part of their internal climate risk analysis, disclosures, and risk management. These

[4] See https://www.ngfs.net/en

scenarios reference local data and modelling, which provide best available data and models for South Africa. These are deemed most applicable for firms to use in climate related risk scenarios to better understand their exposure to climate risks and to internalise these risks as appropriate to their situation.

1.13. The International Actuarial Association recommends the following when designing and choosing scenarios: exposure must be measured on a combination of climate change outcomes; the possible impact on the financial sector must be calculated; risks and opportunities associated with the future environment must be appreciated; and resilience testing must be on extreme weather events. The financial impact of climate-related scenarios should be examined on several emissions pathways. Firms should be allowed to start with various reference scenarios and enhance them spatially and temporally to suit their business models while remaining harmonised with the global scenarios. Importantly, firms should assess the financial implications of each scenario. The following are examples of some of the variables that need to be defined and considered before estimating the impact of different scenarios are: physical variables such as global and regional temperature pathways, severity and frequency of climate-related weather events; transition variables such as carbon pathways, emission paths, energy prices (including renewables) and the energy mix; macroeconomic variables such as GDP and investment; social indicators such as inequality and poverty; and financial market variables, which include government bond yields, corporate bond yields, equity indices and exchange rates.

1.14. The NGFS and the Climate Financial Risk Forum, in their 2020 Scenario Analysis Guide highlighted key challenges in developing climate risk scenarios. Firstly, given the far-reaching impact of climate change in breadth and magnitude, such that climate change will affect all economic participants, across entire sectors. Secondly, although there is certainty that some combination of physical and transition risks will emerge, the pathways and timing remain ambiguous. Thirdly, transition risks are more imminent, but at the same time, the frequency and severity of extreme events is increasing. Fourthly, the future impacts of climate change depend on actions taken today. Fifth, there is a need for new data and modelling techniques to account for the effects of climate change on the economy. Lastly, the effects of related risks must be considered, such as biodiversity loss. These challenges suggests that initially scenario analysis will be used mainly as a communication tool to highlight climate related risks.

1.15. It is therefore important for policymakers to plan beyond traditional political and business strategy planning horizons. The policies should span decades and ideally be implemented in a gradual, progressive manner.

1.16. The remainder of this document is structured as follows: Section 2 and 3 discuss the NGFS scenarios and how they relate to the national set of scenarios run using national models; and the transmission channels. Section 4, 5 and 6 present the transition and physical risk scenarios. Each section describes the frameworks used to generate the scenarios and provides references to detailed model descriptions.

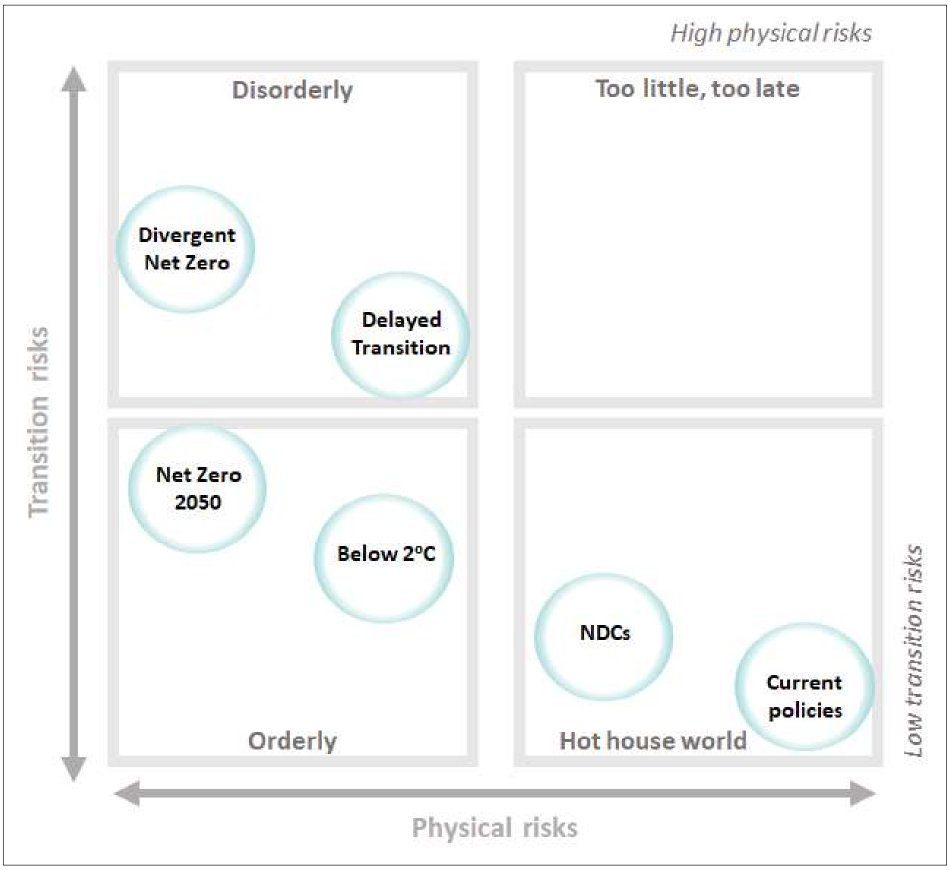
2. NGFS Climate Change Scenarios

2.1 The NGFS currently provides six future climate and transition pathways as a common starting point to assess climate-related financial risks. There are no extreme[5] event scenarios. The framework, illustrated in Figure 1, organises these scenarios according to the transition risks, which include the coordination and strength of policy interventions and investment in technologies, as well as climate outcomes and associated physical risks.

2.2 In terms of transition risks and the framework deployed for the analysis thereof, existing scenarios match relatively well. Firstly, in the scenarios described in the transition risks section immediately below, the reference scenario is not “current policies”. Rather, the reference scenario modelled for South Africa is least cost decision-making (no explicit positive or negative climate policy). The least cost scenario is currently aligned to South Africa’s Updated NDC upper target. As will be emphasised in section three, least cost power generation in South Africa results in substantial mitigation compared with currently deployed technologies due to the quality of South Africa’s wind and solar resources combined with its relatively sophisticated transmission network. The remaining three orderly scenarios match closely with the three scenarios of climate policies modelled and compared to the model-based reference.

[5] The word extreme in this context refers to events that happen once in every 50 or 100 years. These are extreme in terms of the size of the event. The word extreme refers to acute physical climate risks, e.g. droughts or floods.

Figure 1 NGFS scenarios framework



Source: NGFS, 2021

2.3 The transition risks section does not contain disorderly scenarios because the match between existing modelled scenarios and NGFS is not as tight. However, it is straightforward to develop and run disorderly transition scenarios that match closely to the NGFS drivers. For the analysis of physical risk, a framework labelled Systematic Analysis for Climate Resilient Development (SACReD) is deployed. The SACReD scenarios depicted below are roughly aligned to four of the six NGFS scenarios. This correspondence is mapped in Table 1, but the details require a somewhat lengthier set of explanations.

2.4 The current set of scenarios highlight the work that has been done to date, and in future, additional transition risk scenarios will be conducted to align with the NGFS. These scenarios were chosen as a national set of models which consider global conditions provide for a thorough and deeper analysis of domestic impacts than the models currently used for the NGFS scenarios-which are run at the global scale and therefore do not accurately capture country level impacts. While the scenarios currently available using the SACReD framework do not match 1-to-1 with the NGFS scenarios the tool is available to further develop better aligned scenarios in future work.

2.5 The economic evaluation of climate change impacts under South Africa's Long-Term Adaptation Scenarios (LTAS) Programme (Department of Environmental Affairs, 2016) assessed climate futures under two global emissions scenarios. For each scenario, the biophysical and economic models used a sample of 367 climate projections. The unconstrained emissions (UCE) scenario considers that global policies do not reduce emissions. This corresponds essentially to the NGFS Current policies scenario, which assumes no changes or implementation of mitigation policies and measures.

2.6 The LTAS Level 1 stabilisation (L1S) scenario assumes that policies are successful in reducing future warming, but global temperatures continue to rise as a legacy of current emissions. The L1S policy scenario targets a CO2 concentration close to 480 parts per million (ppm). This implies that the increase in annual mean surface temperatures is limited to around 1.6 °C by the end of the century. This aligns roughly to the NGFS orderly Net Zero 2050 scenario, which aims to limit global warming to 1.5 °C through strict climate policies and rapid technological change to reach global net zero emissions in CO2 by 2050.

2.7 More recent applications of the SACReD framework to Southern Africa consider four scenarios to describe a range of possible global actions against which climate risks are explored. In each scenario, 455 climate projections are used (Schlosser et al., 2020; Arndt et al., 2021). The scenarios considered are:

2.7.1 The Reference scenario (REF), akin to the LTAS UCE and NGFS Current policies scenario, assumes no explicit mitigation policies anywhere in the world, except for some energy policies that are presently occurring.

2.7.2 The Paris Forever (PF) scenario is aligned to the NGFS Nationally Determined Contributions (NDC) scenario. Under PF, countries meet and commit to mitigation targets outlined in their Nationally Determined Contributions, through to the end of the century.

2.7.3 The 2C scenario limits warming to a 2 °C global average by the end of the century. Under this scenario, smooth, coordinated increases in the carbon price encourage a reduction in emissions, but variations in mitigation policy create differences in technology and resource use. Still, the overall probability of achieving the target is 66%[6]. The 2C scenario corresponds with the NGFS Below 2 °C scenario.

2.7.4 Similarly, a 1.5 °C scenario (1.5C) is also considered, aligned to the NGFS Net Zero 2050 scenario.

[6] Reference IPCC: https://www.ipcc.ch/sr15/chapter/spm/.

Table 1 Mapping of NGFS scenarios to close analogues based on SACReD studies for South Africa

NGFS scenarios	SACReD analogous scenarios	SACReD analogous scenarios
Current policies	Unconstrained emissions (UCE)	Reference (REF)
NDCs	-	Paris Forever (PF)
Below 2C	-	2C
Net Zero 2050	Level 1 stabilisation (L1S)	1.5C
Divergent Net Zero	-	-
Delayed Transition	-	-

Source: NGFS scenarios (NGFS, 2021); SACReD analogous scenarios (Department of Environmental Affairs, 2016; Cullis et al., 2015; Hartley et al., 2021); SACReD analogous scenarios (Schlosser et al., 2020; Arndt et al. 2021)

2.8 The next sections focus on physical risks and results from both the earlier and more recent iterations of the SACReD framework are presented. A part of the ongoing SARB research program is to update the economic models underlying SACReD. Hence, economic results are drawn from the earlier analyses listed in column two of Table 1. In contrast, much of the climate and biophysical work under the new iteration is complete. Examples from this more recent work are presented.

3. Transmission channels: physical and transition risks

3.1 There are two distinct elements in the transmission mechanism linked to mitigation and adaptation. The first relates to physical risks, defined as risk associated with the materialisation of climate change events. The second is linked to risks associated with the transition to a low-carbon economy. Arndt, Loewald, and Makrelov (2020) provide a detailed discussion of how these risks impact the economy generally, as well as the financial sector. Physical and transition risks give rise to social risks and vulnerabilities, including lives and livelihoods, loss of jobs, influencing local economic development, broader economic activity, and financial assets. In South Africa, social risks are elevated since both physical and transition risks affect vulnerable communities. The Just Transition framework, recently developed by the Presidential Climate Commission, and the Just Energy Transition Investment Plan, relate to climate risk management and the financial sector. Particularly for this purpose, the financial sector is encouraged to build resilience to transition risks while ensuring that social consequences imposed by transition risks are mainstreamed into the risk management and investment approaches. As transition pathways and scenarios are developed, the social risks will need to be incorporated, initially qualitatively and over time, quantitatively. The scenarios presented in this report do not cover social risks.

Physical risks

3.2 Physical risks comprise the effects of hazard, vulnerability, and exposure. In the near term, physical risks are mainly posed by the growing severity and frequency of climate-related weather incidents (acute risks) as well as chronic climate factors such as temperature, precipitation, and sea level rise. These events damage property and infrastructure, affect agricultural production, disrupt business supply, and often result in loss of life. The economic costs from climate change include changes in physical capital; damage to infrastructure; destruction of natural capital - sea levels affecting the availability of land; deterioration of health and living conditions of human capital; impacts on labour productivity, particularly in outdoor activities, reduced investment - due to reservations about future economic growth; and the indirect effects of global and regional climate change causing supply chains disruptions. The country can invest to make infrastructure climate resilient but not climate-proof. While some of these risks can be addressed by adaptation, this requires careful economic assessments of future benefits versus present costs.

3.3 Beyond the direct (physical damage of assets) and indirect (impact through the supply chain) risks, financial impacts may also propagate through the exposure of the financial sector to the real economy (e.g., households, companies, sectors, and countries) (Hubert et al., 2018). The direct exposure of a financial institution's operation (through physical assets, labour, or dependence to natural resources) may represent only a small percentage of their exposure to the risk. At a system level, inflation, growth, interest rates and productivity are all likely to be affected by physical risks (Bank of England, 2021).

3.4 Increased credit risk for banks will occur through counterparties exposed to physical risk. Chronic and acute physical risks will impact profitability through direct and indirect impacts increasing the probability of default on loans. Overall, this may diminish asset values while affecting the long-term credit worthiness of counterparties. This in turn may increase collateral requirements requested by banks. Acute and chronic physical risks can result in abrupt changes in pricing. For example, a tipping point that results in fire-sales of properties with exposure to flood risk. This may also lead to uncertainty in insurance markets owing to claims volatility for corporates accessing business interruption lines. The change in weather patterns regionally will translate into economic changes and productive capacity and ultimately changes in supply and demand of different products and commodities.

3.5 Investment risk will accrue for physical assets across all sectors, which are exposed to physical risks at varying levels depending on their combination of exposure, susceptibility, and adaptive capacity. Investment risk will decrease asset value affecting collateral against loans thereby increasing the risk of default. Investment risk is a concern for institutional investors, government, and government-own financial institutions who may invest in long term physical assets that will have exposure to future climate risks.

3.6 Climate change will likely increase the frequency and severity physical risks and coupled with geographical concentration risk, will likely translate into increased claims. Natural catastrophic risk is typically well understood with the annual adjustment of premiums allowing the insurance sector to respond rapidly to changes in climate risk exposure. If climate risk is not appropriately integrated into underwriting processes, the insurance sector may face greater exposure. In the long-term, it is likely that insurance and reinsurance become more expensive with product offerings being limited in areas that face high exposure. This will also result in less diversification in the sector increasing the likelihood of previously uncorrelated risks. Ultimately, this may also place more pressure on national governments to assist disaster risk financing efforts if some risks become uninsurable. The uncertainty related to the severity of extreme events make it difficult to determine actuarially fair insurance policies. Further research is needed to understand the required role of insurance in these cases and the institutional frameworks needed to enable the sector to act in this role.

Transition risks

3.7 Transition risks arise from a transition to a low-carbon economy and its effects on the value of assets and liabilities as well as on income flows. Transitioning to a low-carbon economy will require structural changes in the economy, compelling the reallocation of investments. The market value of some heavy polluting industries could be adversely affected by policy measures and market trends towards a low-carbon economy. However, the transition to a less carbon-intensive economy also presents opportunities.

3.8 The potential benefits include technological spillovers, reduced dependence on natural resource sectors, enhanced energy security, and improved health through reduced air pollution (Krogstrup and Oman, 2019). These co-benefits can create new jobs and industries, increasing the medium-to-long-run benefits of mitigation (Groosman, Muller and O'Neill-Toy, 2011). However, a delayed or abrupt enactment of climate-related policies to reduce carbon emissions can result in large asset price declines, increases in stranded assets and financial instability, resembling a Minsky moment[7] (Batten, Sowerbutts and Tanaka, 2016; and Carney, 2015).

3.9 South Africa is significantly exposed to climate transition risks due to a significant investment in CO_2-intensive sectors. The country ranks 13th globally in terms of total CO_2 emissions. Electricity generation accounted for 56% of CO_2 emissions in 2015. This is due to the high prevalence of coal-fired, low-

[7] A Minsky moment refers to the onset of a market collapse brought on by the reckless speculative activity that defines an unsustainable bullish period.

cost[8] power generation in the country. This increases the carbon intensity of all sectors, particularly those that are export-intensive, such as mining and manufacturing (Arndt et al., 2013). Reducing carbon emissions requires a reduction in the production and consumption of high-carbon products such as fossil fuels, a fall in energy intensity, and a move to low-carbon energy production (Batten, 2018). The transition requires a combination of policies, which can lead to large structural changes, negatively affecting many mining communities, and firms and workers in energy-intensive sectors (IMF, 2019).

3.10 Price-based instruments push transition risks (and transition costs) in the economy by reducing profitability for carbon-intensive firms and increasing prices to consumers and firms for carbon-intensive commodities. South Africa implemented a national carbon tax, which stood at USD 8/tCO2, in July 2019. The tax covers combustion emissions, industrial processes, product use emissions, and fugitive emissions[9] such as those from coal mining. Its immediate impact is likely to be limited, as up to 95% of emissions are eligible for exemption during the first phase, until 2022. To effectively limit global warming to the goal of 2°C, the government would in 2023 lift the exemptions that are currently allowed, and the tax rate would be increased to USD 75/tCO2. This would change relative returns in the economy, guiding investment in new technologies.

4. Transition scenarios and risks

4.1 Transition risk faced by South Africa arises from different sources, these include: a) the stranding of capital and labour as a result of changes in the structure of the economy as some activities (such as coal mining) are not compatible with the set greenhouse gas (GHG) mitigation goals; b) underinvestment in new and emerging technologies (and the associated necessary human capacity) required for the transition and the potential system-wide impacts (an example is insufficient investment in new low carbon power generation capacity in time to replace phased out coal which could lead to increased load shedding); and c) penalties by trading partners that account for embodied emissions[10] of exported goods. A high level of embodied emissions for goods produced in an economy which doesn't transition at the expected pace, could result in lower competitiveness and reductions in exports, which would pose a risk to investments made in the exporting sectors.

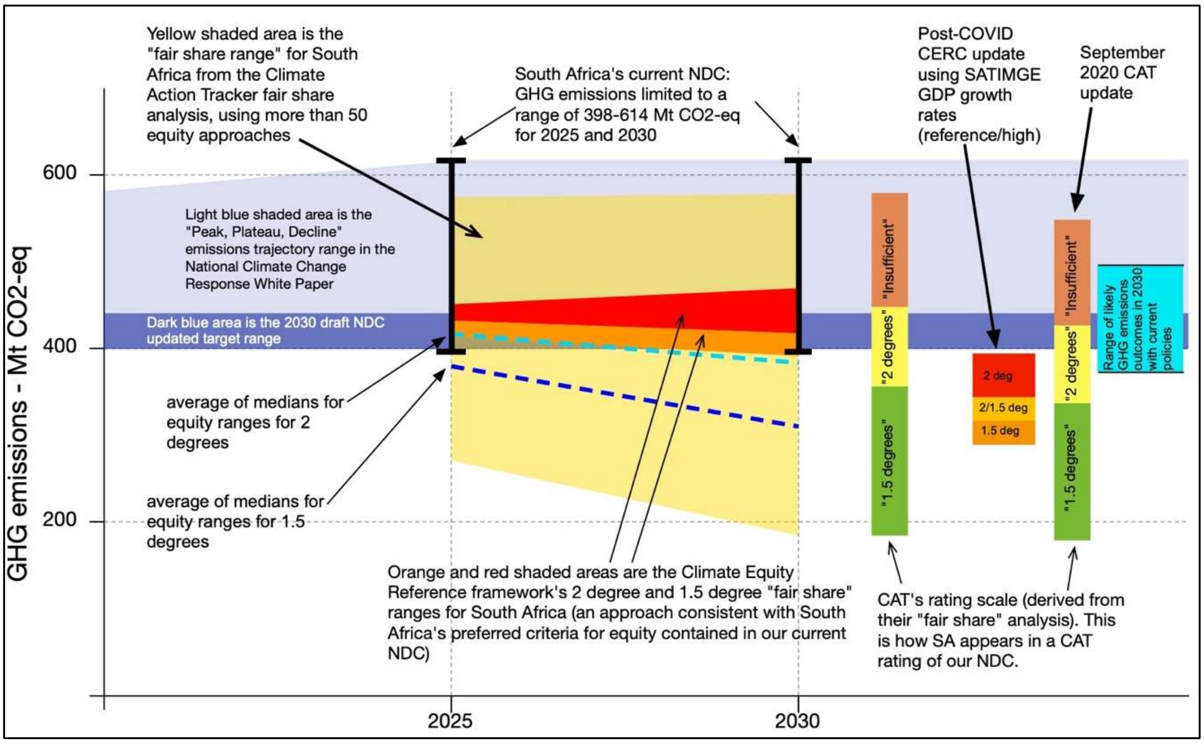
4.2 Aligning country mitigation targets to global mitigation objectives is a challenging task as the share of country responsibility in global emissions

[8] It is debatable whether whether coal-fired power generation is still "low-cost", given the significant and continuing decrease in the costs of renewable energy as well as rising coal fuel costs due to rising transport and mining costs (deeper coal mining is required for the extraction of the resource).
[9] Fugitive emissions are unintentional leaks emitted from sealed surfaces, for example from pipelines.
[10] Embodied GHG Emissions: Embodied carbon means all the GHG emitted in producing goods (from extraction and transport of raw materials as well as direct and indirect emissions from manufacturing processes).

reductions must account for both responsibility but also capability given different national circumstances and national targets for sustainable economic development, which includes decreasing poverty and inequality, to be fair (UNFCCC 2018). To date consensus on estimates of fair share contributions for countries have not been determined.

4.3 The South African Nationally Determined Contribution (NDC) has developed an accepted fair share contribution to global mitigation by 2030. This is illustrated in Figure 2 where the dark blue area indicates the country's Updated NDC. As illustrated in the figure the NDC lies within the range of most estimates of fair share contributions for South Africa. The technical analysis underpinning the South African Updated NDC (Marquard et al. 2021) shows that with existing mitigation policies and measures, South Africa can meet the fair share contribution and its Updated NDC.

Figure 2 South Africa's "fair share" equity lens for the NDC update, 2025 and 2030, with updated "fair share" Climate Action Tracker (CAT) (post September 2020) and Climate Equity Reference Calculator (CERC) (May 2021) ranges



Source: Marquard et al. 2021

Note: The May 2021 CERC range here is derived from a sensitivity analysis using SATIMGE growth rates as described above. The single bar (with 2, 2/1.5 and 1.5 divisions) combines the reference and high growth rate sensitivity analyses. The 2/1.5 block is where the two ranges overlap. The bar on the right indicates a range of likely GHG outcomes in 2030 with different growth rates and degrees of policy implementation, of the implementation of currently planned policies as modelled with SATIMGE.]

4.3.1 The Updated NDC defined fair share contribution, however, does not account for emissions beyond 2030. Understanding fair share emissions reductions required under the longer term to 2050 requires a cumulative view of emissions over the period. It is estimated that a cumulative total GHG emissions target of between 7 and 8GT over the 2021-2050 period would be considered a fair share contribution, although further work around this is still needed.

Scenarios and Assumptions

4.4 To illustrate the transition risks associated with decarbonising the economy we present two scenarios, a Reference scenario and a 7GT scenario. The 7GT scenario is considered an extreme mitigation scenario as it is very ambitious for South Africa given current technologies and policies.

4.5 **Reference scenario**: Under the Reference scenario emissions are not limited nor are there any limitations in place on the shares of new technologies included in the energy technology mix. The energy model is thus allowed to optimize to find the least cost path for meeting energy demands in the economy. A moderate average annualised real economic growth rate of 2.8% is assumed and no significant changes in the structure of economy are included[11]. The economic growth projection includes the impact of the COVID-19 pandemic as well as the most recent forecasts of economic growth at a point in time (Marquard et al., 2021). No global punitive measures, due to low climate mitigation, are included. The Reference scenario is consistent with the NGFS current policies and NDCs[12] scenarios.

4.6 **7GT scenario**: The 7GT scenario is used to highlight the transition risks related to energy mitigation. In this scenario, total cumulative GHG emissions between 2021 and 2050 in the economy is limited to 7GT and net-zero CO2 is achieved by 2050.

4.7 The South African TIMES-CGE (SATIM-GE) model, an energy-economic linked model for South Africa is used for the analysis. SATIM-GE links the Integrated Markal Efom System (TIMES) model for South Africa, a bottom-up integrated energy systems model that captures full sector energy supply and demand, with the South African General Equilibrium (SAGE) model, an economy-wide dynamic recursive computable general equilibrium model. More information on the individual models and the linked modelling system can be found in Arndt et al. (2016), Merven et al. (2019a, b) and Merven et al. (2020a, b).

4.8 The assumptions across the two scenarios are kept the same, with the only difference being the emissions cap under the 7GT scenario. The key assumptions included in the analysis are outlined below.

[11] The economic growth rate reflects the reference growth projection used in the NDC update. The growth rate is based on the National Treasury 3 year outlook from the 2020 MTBPS and the IMF's long term forecast available at that time. The average growth rate is to 2050. The model includes other growth scenarios and is in the process of being updated with the most recent historical and forecasted data.

[12] The 2030 updated NDC commits South Africa to reducing emissions in 2030 to between 350 and 420Mton CO_2-eq per year by 2030.

4.8.1 Available technologies: In addition to standard available technologies for South Africa, the analysis also includes the potential for hydrogen for hard to decarbonise sectors although no major hydrogen-based products or economy is included in the scenarios presented here.

4.8.2 Technology costs: Moderate assumptions on solar PV (photovoltaic) and wind costs are included in line with the costs used in the Integrated Resource Plan. Learning is assumed for renewable energy, batteries, and electric vehicles (see Merven et al., 2020a). This means that the cost of the technology decreases as the global cumulative installations increase, due to factors such as learning-by-doing and economies of scale. Electric vehicles are assumed to reach cost parity with traditional internal combustion engines by 2030.

4.8.3 Retirement of existing capacity: Existing power capacity is allowed to endogenously retire based on relative costs to other technologies. Endogenous retirement is also possible for refinery capacity although this is limited to post-2028 for crude oil refineries and post-2035 for coal to liquid.

4.8.4 Fossil fuel exports: Coal exports are assumed to moderately decline by 4% per annum in line with the change in global preference for cleaner energy fuels.

4.8.5 Economic: The Reference scenario assumes a real economic growth rate of 2.8% per annum on average. The underlying assumptions leading to this growth rate (e.g., total factor productivity, foreign investment) is kept the same across scenarios, although in the 7GT scenario changes in the energy sector resulting from the emissions cap affect prices and behaviour impacting the growth rate in the economy. The population is assumed to grow by 0.8% per annum (average) from 59 million in 2020. Population projections are based on data from StatsSA (2020) and the United Nations (2019). Energy investment is assumed to be financed from existing funds available in the country.

4.8.6 Non-energy emissions: A 20GT CO2 sink is assumed to be provided by the land sector by 2050.

4.8.7 Other: A real discount rate of 8.2% is assumed as per government planning documents. The international oil price is taken from the 2020 International Energy Agency (IEA) World Energy Outlook (IEA, 2020) and is assumed to reach USD50 per barrel in 2050.

4.8.8 Global energy and emission changes are not directly included although projections of key commodities such as the price of oil and coal as well as the demand for coal is included. These assumptions are in line with a moderate global emissions decline.

Changes in energy and emissions pathways

4.9 Under the Reference scenario, emissions in South Africa decrease by 3% by 2030 and 31% by 2050 relative to 2020 (Figure 3). Between 2021 and 2050 cumulative emissions are 10GT. The decrease in emissions is primarily driven by the energy sector, specifically the power sector, as the share of renewable energy increases and the share of coal decreases (Figure 4). The switch to renewable energy is driven by lower relative technology costs and is a consistent finding across several studies including Wright et al. (2017), Reber et al. (2018) and Merven et al. (2020).

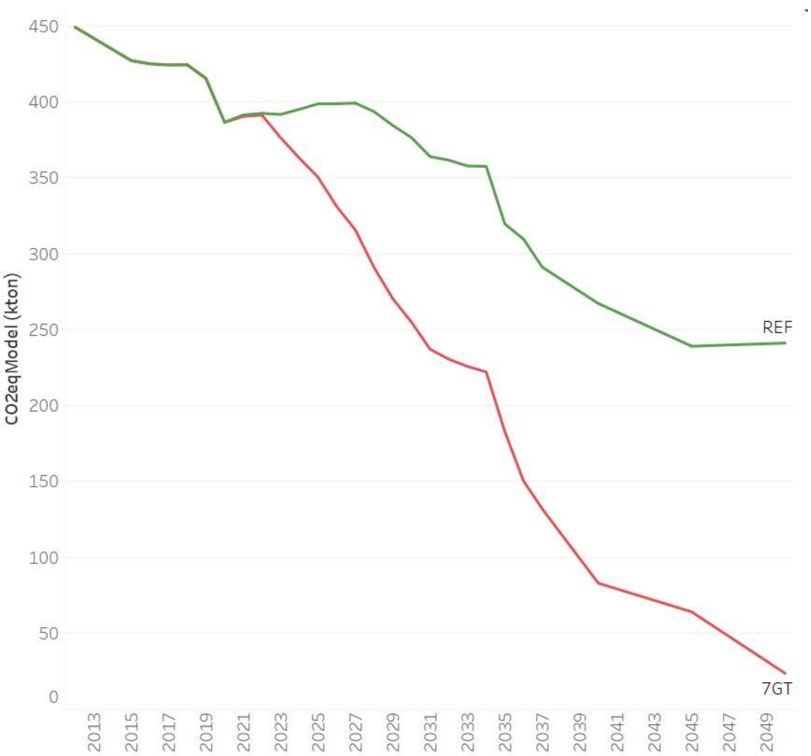
4.10 Under the 7GT scenario, total CO2-eq emissions decrease at a faster pace to meet the emissions cap over the 2021-2050 period. Total emissions decrease significantly in the 2020s already, compared with the late 2030s in the Reference scenario, with more significant declines in emissions also occurring in the late 2030s. By 2030 and 2050, total emissions are 32% and 85% lower than in 2020. Under this scenario, net zero CO2 (but not CO2-eq[13]) emissions is achieved by 2050. Unlike the Reference scenario, emission reductions are also needed outside of the energy sector in the 7GT scenario. By 2050, Industrial Processes and Product Use (IPPU) and Agriculture, Forestry and Other Land Use (AFOLU) emissions decrease by 84% and 33% relative to 2020 compared to increases of 15% and 32% the Reference scenario.

4.11 Declines in energy emissions under the 7GT scenario are driven by a faster decrease in the use of coal in total primary energy supply (relative to the Reference scenario) as well as lower petroleum product and gas use. As a share of total primary energy supply, coal accounts for 54% by 2030 and 5% by 2050 compared with 74% in 2020; and 70% and 29% in the Reference scenario[14].These energy sources are replaced primarily by renewable energy sources, namely solar PV and wind, as power generation shifts to incorporate more of these technologies and the economy becomes more electrified. An example of this is the change in fuel use within the transport sector toward electricity for both passenger (private and public) and freight road transport (light commercial vehicles). The fuel shift in the freight road transport sector is however dominated by a shift to hydrogen for heavy commercial vehicles.

[13] GHG emissions comprise of CO_2, methane and nitrous oxide emissions. Methane and nitrous oxide emissions are first converted to CO_2 equivalent emissions and then added to CO_2 to get total CO_2-eq emissions. In reaching net-zero CO_2 emissions, but not net-zero CO_2-eq means that there are still methane and nitrous oxide emissions, mainly coming from the agricultural sector.

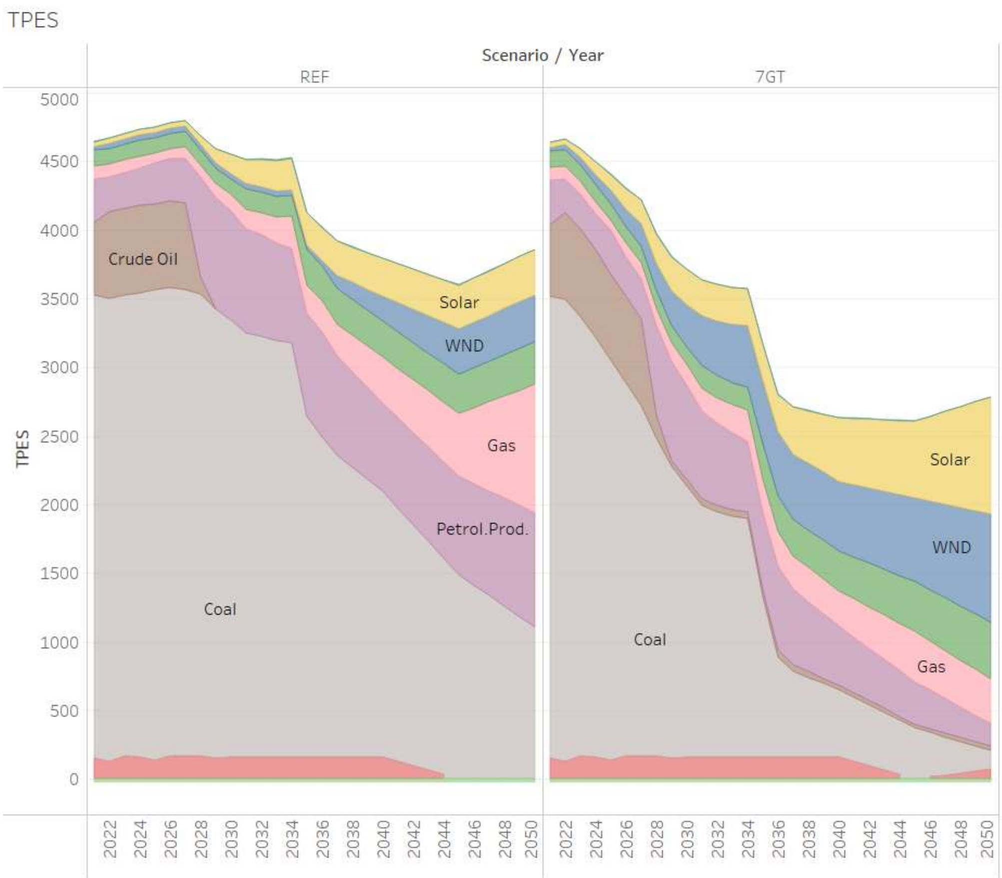
[14] As a share of total primary energy supply, petroleum products account for 19% and 6% by 2030 and 2050; and gas accounts for 4% and 12%. The shares of petroleum products and gas are 9% and 2% in 2020. In the Reference scenario petroleum products account for 18% and 22% of total primary energy supply in 2030 and 2050; and gas 3% and 24%.

Figure 3 Total CO2eq emissions, 2020-2050



Source: Energy Systems Research Group

Figure 4 Total Primary Energy Supply, 2020-2050



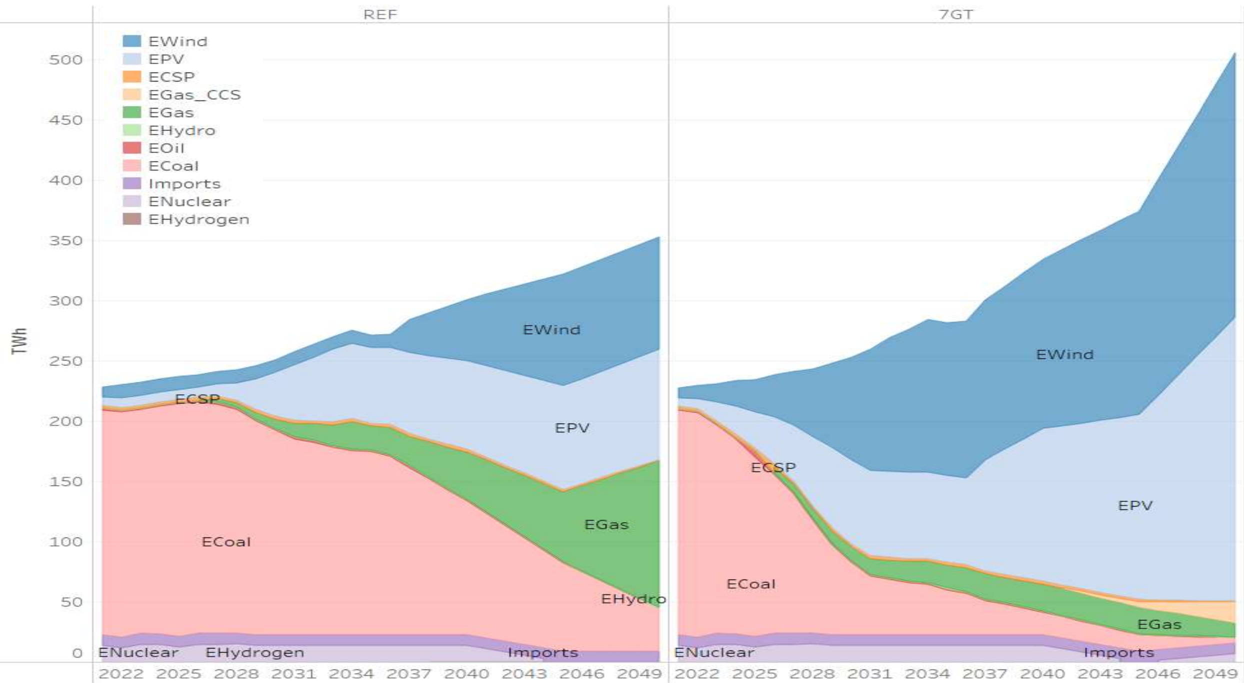
Source: Energy Systems Research Group

4.12 Figure 5 shows the change in electricity generation for the two scenarios. As noted, in both cases there is a shift toward solar PV and wind and a shift out of coal use for power generation. The transition out of coal starts earlier in the 7GT scenario with coal accounting for only 24% of power generation by 2030 and 1% by 2050 compared with 68% and 10% in the Reference scenario. Solar PV and wind account for 61% and 90% of power generation in the 7GT scenario by 2030 and 2050 respectively (Reference: 19% and 23%). In 2020, coal accounts for 82% of production. In the 7GT scenario there is also a shift out of gas in the power sector. Carbon capture and storage on gas is needed after 2040 to reach net zero CO2 and the cumulative emissions target.

4.13 In both the Reference scenario and the 7GT scenario, the energy transition leads to the stranding of coal power assets. This is more severe under the 7GT scenario as some plants, namely Camden, Kendal, Kriel, Majuba Dry and Wet, Sasol Infrachem and Tutuka, are decommissioned earlier relative to the Reference scenario.

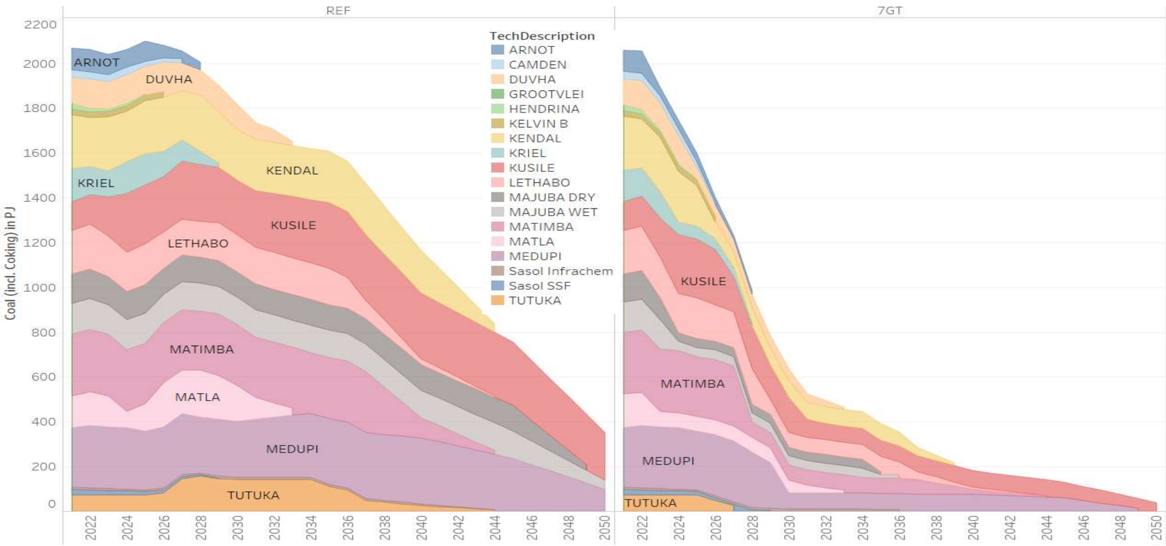
4.14 Implications for coal demand from the power sector by plant is presented in Figure 6. Total coal demand from the power sector decreases from 2,060PJ in 2020 to 1,817PJ and 351PJ in 2030 and 2050 in the Reference scenario; and 637 and 37PJ in the 7GT scenario. Understanding the full supply chain of coal to these power plants from the company level could provide important insights into the transition risk for companies in several sectors including coal mining and transport. Further information is needed however to link individual plants and their supply value chains.

Figure 5 Power generation by technology type, 2020-2050



Source: Energy Systems Research Group

Figure 6 Coal demand by power plant, 2020-2050



Source: Energy Systems Research Group

Cost implications of the climate transition

4.15 Increased investment in power generation is needed to ensure that supply can meet demand. In the Reference scenario, cumulative power sector investment of R1,820 billion (in 2015 Rands) is needed until 2050. Under the 7GT scenario, the level of cumulative investment is nearly double (R3,549 billion). The larger investment requirement is driven by the faster shift to renewable energy in the 7GT scenario, as well as the higher level of demand for power as the economy becomes more electrified (Figure 5). Figure 7 presents the cumulative level of investment for the Reference and 7GT scenarios.

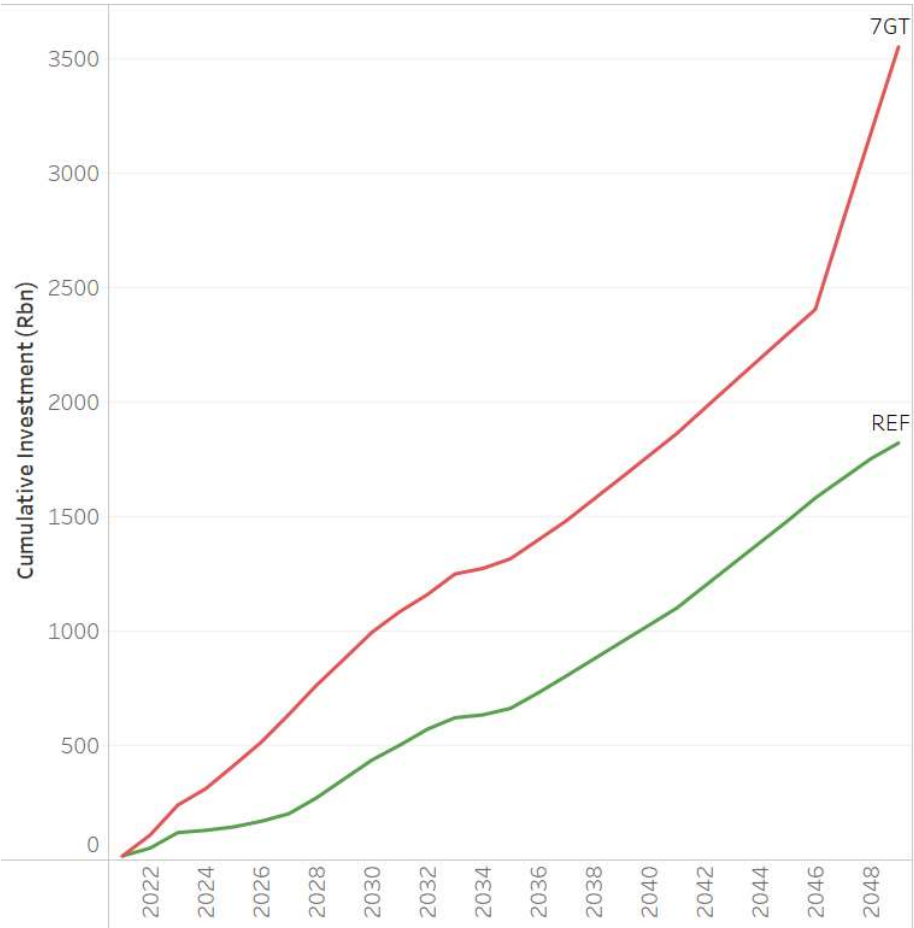
4.16 The bulk price of electricity (Figure 8), measured as the cost of supply divided by the level of demand, also increases. In the Reference scenario the electricity price (real 2019 Rands) is 2.9% higher by 2050 relative to 2020. In the 7GT scenario, the price increases by 10.6% by 2050 relative to 2020 and is 7.5% higher than in the Reference scenario[15]. While not explicitly modelled in the current scenarios, an implied carbon tax can be calculated for each of the scenarios. Under the Reference scenario, the effective carbon tax aligns to the 2019 Carbon Tax Act (RSA 2019) reaching R26.10/ton by 2022 in 2015 Rands (from R24.60) and remaining constant at this level in real terms to 2050.[16] A significantly higher carbon tax would however be needed reach the 7GT

[15] Prices decreases in the reference and 7GT scenario from 2045 are due to declines in the cost of renewable energy because of learning. The 7GT price remains above that of the Reference as more capacity is needed to meet the higher level of electricity demand. Annual repayments for Medupi and Kusile and REIPPP are already factored in 2020 costs. Transmission and Distribution costs are calibrated to historical expenditure by Eskom and does not reflect backlog in the municipal spending on maintenance and investment in distribution network.

[16] The National Treasury released an update to the Carbon Tax trajectory in its 2022 Budget Review. This has not been included in the scenarios presented here. This number refers to the effective carbon tax rate in 2015 Rands and accounts for allowed exemptions. The figure in 3.3.4 is consistent with the nominal rate quoted excluding exemptions.

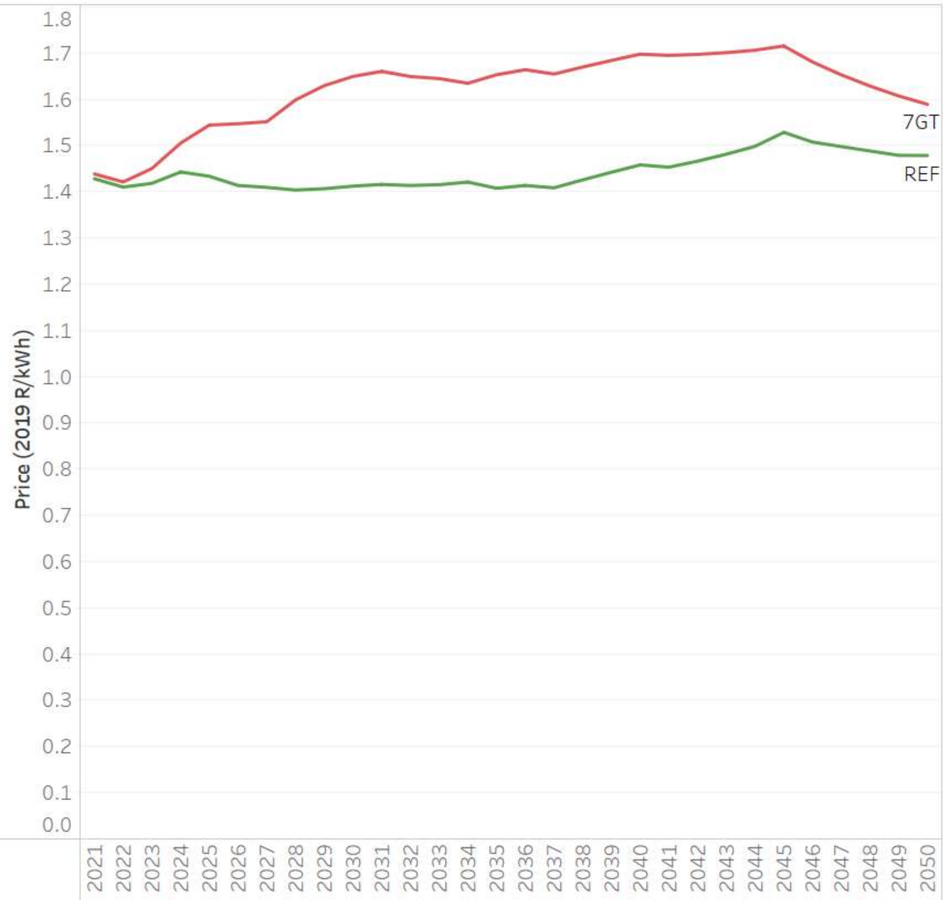
cumulative mitigation target. On average the carbon tax would need to increase by 23% per annum from 2020 to reach R479/ton by 2030 and R1,057/ton by 2040. In 2022, Treasury provided in the Budget Review a table of the carbon tax in rand terms based on an average rate of R15.40/$ for the 12 months to end-July 2022, which it said would translate into a carbon tax of R159/tonne of CO_2 emissions in 2023. This would rise to R190 in 2024, R236 in 2025, R308 in 2026 and R462 in 2030.

Figure 7 Cumulative power sector investment, 2020-2050



Source: Energy Systems Research Group

Figure 8 Bulk electricity price, 2020-2050

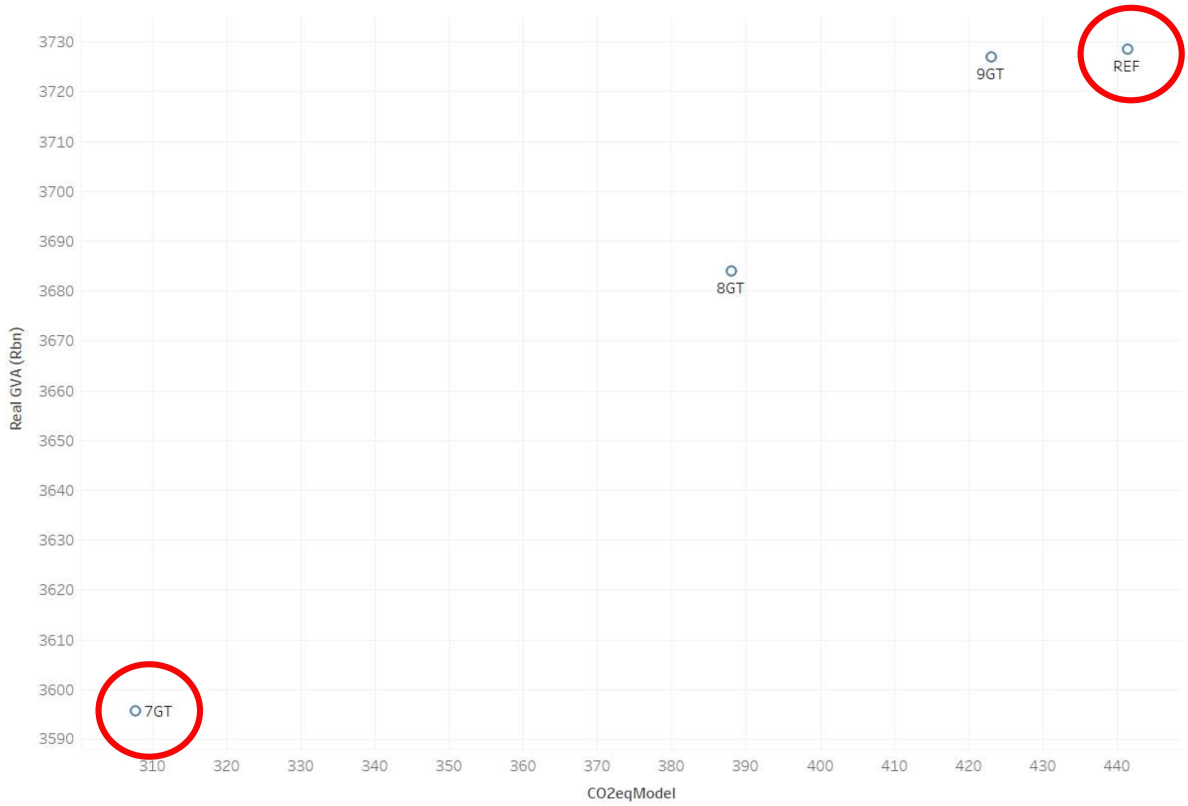


Source: Energy Systems Research Group

Impact on economic development

4.17 As mentioned in the Scenarios and Assumptions section, an average annual real growth rate of 2.8% is assumed in the Reference scenario with no punitive measures included for South Africa's low climate ambition. No significant changes are assumed to the economic structure of the economy in the Reference scenario, and this allows for comparison with the mitigation scenarios where there are structural changes. Under the 7GT emissions constraint, real economic growth slows to an average annual rate of 2.5%. By 2030 and 2050, the level of real (GDP) is 3.6% and 8.5% lower than in the Reference scenario. The decrease in economic activity is primarily driven by the higher level of investment needed in the energy sector which crowds out investment in other sectors of the economy. Foreign financing of the energy transition can therefore aid in reducing the cost of mitigation on the economy and hence some of the transition risk associated with climate mitigation. Figure 9 presents the trade-off between economic growth and emissions for different cumulative emissions scenarios. The Reference and 7GT scenarios discussed here are circled in red.

Figure 9 Real gross value added (GVA) and emissions level (excluding Land Use, Land Use Change and Forestry (LULUCF)), 2030



Source: Energy Systems Research Group

4.18 Declines in value added, relative to the Reference scenarios, are largest in the mining and manufacturing sectors, although production in all activities decreases. In terms of the structure of the economy, the GVA shares of the services, food and beverages, and agriculture sectors increase whilst there is a marked decrease in contribution from the mining, non-ferrous and chemicals sectors.

4.19 Employment is 3% lower by 2030 with 500,000 fewer jobs created in the 7GT scenario relative to the Reference scenario. By 2050, employment is 6% (2 million) lower than in the Reference scenario. These numbers are calculated as the total number of jobs in one scenario relative to the other at a specific point in time. The number of people employed is an outcome of the model which includes labour supply elasticities. Fewer employment opportunities are created across most sectors in the 7GT scenario, although the power sector and other new technology sectors such as hydrogen create more employment opportunities. The loss of employment opportunities is larger for unskilled (primary and middle school educated) than skilled workers.

4.20 A deterioration in the trade balance is experienced under the 7GT scenario (relative to the Reference scenario) as activity decreases and South African competitiveness declines due to the rising costs of production. The transition to cleaner energy does, however, translate into a smaller net energy trade balance due to less dependence on imported liquid fuels and crude oil.

Coal mining and the climate transition

4.21 The coal mining sector is one of the key sectors affected by the climate transition because of changes in both local and global environments. On the international front, changes in preference for cleaner energy fuels will result in a decrease in South African coal exports. To capture this, a moderate decline in coal mining exports (as the rest of the world reduces emissions) of 4% per annum is included in the two scenarios presented. At the local level, the shift away from coal in the power and refinery sectors under both the Reference and 7GT scenarios decreases the demand for coal. In the 7GT scenario, demand for coal from industry also decreases by 2050 (relative to 2020).

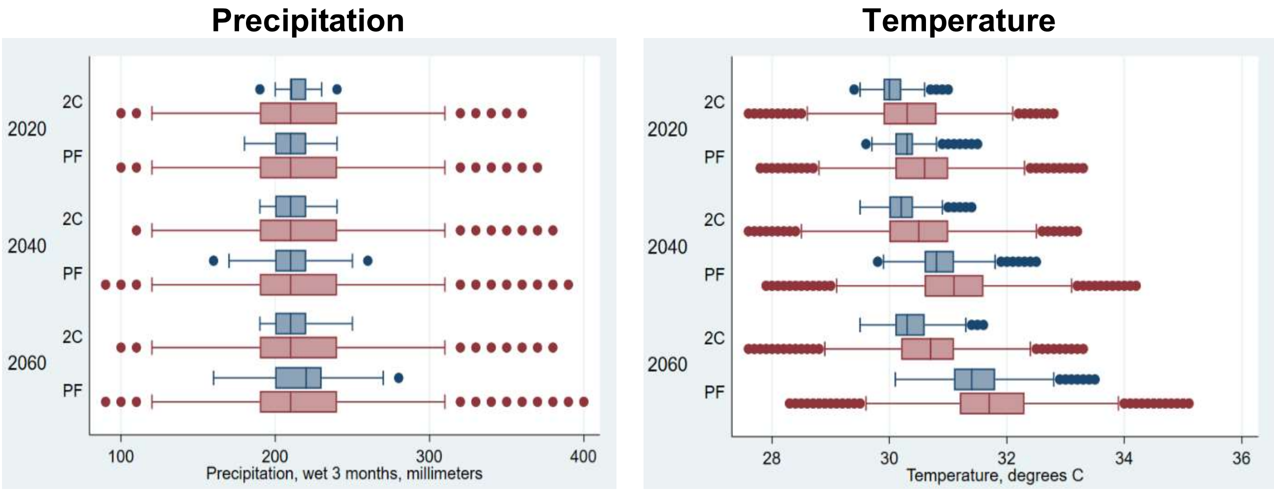
4.22 Total coal demand in the Reference and 7GT scenarios decreases to 197Mton and 133Mtons by 2030, respectively, from 238Mton in 2020. By 2050, coal demand is 69Mton and 26Mton under the Reference and 7GT scenarios. In the Reference scenario, coal mining GVA is 24% lower by 2030 and 61% lower by 2050 (relative to 2020) with the number of jobs provided by the sector decreasing by 15,000 by 2030 and 38,000 by 2050 relative to 2020 (coal employment: ~63,000). The faster shift out of coal in the power and refinery sector as well as declines in use by industry results in a faster decrease in coal mining GVA under the 7GT scenario. By 2030 and 2050, coal mining GVA is 39% and 81% lower than in 2020. Employment losses in the sector are also larger, with 25,000 jobs lost by 2030 and 51,000 jobs lost by 2050.

5. Physical scenarios and risks

Climate Models, Uncertainty, and Variability

5.1 As discussed, the NGFS system offers four levels of physical risk that seem to be associated with four pathways of future greenhouse gas (GHG) emissions. The South African scenarios also have four emissions pathways which can roughly be mapped to NGFS based on the most recent application of SACReD. Within each emissions pathway, however, the South African models have 720,000 climates with monthly data spanning 70 years and defined for each 25-kilometers gridcell. This allows us to not only look at uncertainty from future emissions pathways, but uncertainty surrounding which future climate might occur because of the pathway. These models also consider the effect of inter-annual variability in climate, since for any given climate future, there will be years with good weather, years with normal weather, and years with bad weather – and it is in the bad weather years (or perhaps even normal years in an adverse climate) that physical risks are more likely to be realised and more likely to be large in magnitude.

Figure 10 Comparing distributions showing climate uncertainty with and without inter-annual variability, 2C and PF



Source: Thomas et al. (2021b)

5.2 As illustrated in Figure 10 climate uncertainty with regards to precipitation increases over time and is higher under higher-emissions scenarios such as PF. Inter-annual variability dominates uncertainty in the near-term, but less so further into the future. Climate change has a limited impact on the mean.

5.3 Mean temperatures increase under climate change with higher-emissions scenarios showing larger increases in temperature. As with precipitation, uncertainty increases over time and under higher-emissions scenarios. Figure 10 highlights the importance of inter-annual variability for temperature uncertainty, especially in the near-term.

5.4 Table 2 shows variation of temperature in water management areas (WMAs) in South Africa across multiple decades. This shows substantial spatial heterogeneity both in mean temperatures and in how climate change will impact the country, with inland WMAs showing greater uncertainty and variability than the coastal WMAs.

Table 2 Mean daily maximum temperature for the warmest month in the wettest 3 consecutive months.

Year	Scen	Northeast range		Pongola (NE coast) range		Vaal range		Orange range		Mzimvubu (SE coast) range		Western Cape range		South Africa range	
		50	**(5-95)**	**50**	**(5-95)**	**50**	**(5-95)**	**50**	**(5-95)**	**50**	**(5-95)**	**50**	**(5-95)**	**50**	**(5-95)**
1990	Base[c]	30.8	0.0	27.9	0.0	31.6	0.0	32.1	0.0	27.5	0.0	24.1	0.0	29.4	0.0
2020s	2C[c]	31.4	1.2	28.4	0.8	32.3	1.0	32.8	0.8	28.0	0.7	24.7	0.8	30.0	0.8
2020s	PF[c]	31.6	1.2	28.6	0.9	32.6	1.1	33.1	0.9	28.3	0.8	24.9	0.8	30.3	0.9
2040s	2C[c]	31.6	1.4	28.5	1.0	32.5	1.2	33.0	1.0	28.2	0.9	24.8	0.9	30.2	1.0
2040s	PF[c]	32.2	1.8	29.1	1.3	33.2	1.6	33.6	1.3	28.7	1.2	25.3	1.2	30.8	1.2
2060s	2C[c]	31.7	1.6	28.6	1.1	32.7	1.4	33.2	1.2	28.3	1.0	25.0	1.0	30.3	1.1
2060s	PF[c]	32.9	2.4	29.6	1.7	33.8	2.2	34.3	1.7	29.3	1.5	25.9	1.6	31.4	1.6
2020s	2C[c&w]	31.9	2.6	28.8	2.2	32.7	3.6	33.1	3.3	28.2	1.7	24.7	1.6	30.3	2.2
2020s	PF[c&w]	32.2	2.6	29.0	2.2	33.0	3.7	33.3	3.3	28.5	1.8	24.9	1.7	30.6	2.2
2040s	2C[c&w]	32.1	2.7	28.9	2.4	33.0	3.8	33.3	3.4	28.4	1.9	24.9	1.8	30.5	2.3
2040s	PF[c&w]	32.7	2.8	29.5	2.5	33.6	3.9	33.9	3.5	28.9	2.1	25.4	2.0	31.1	2.5
2060s	2C[c&w]	32.2	2.9	29.1	2.4	33.1	3.8	33.4	3.3	28.5	1.9	25.0	1.8	30.7	2.3
2060s	PF[c&w]	33.4	3.3	30.0	2.7	34.3	4.1	34.6	3.5	29.5	2.3	26.0	2.2	31.7	2.6

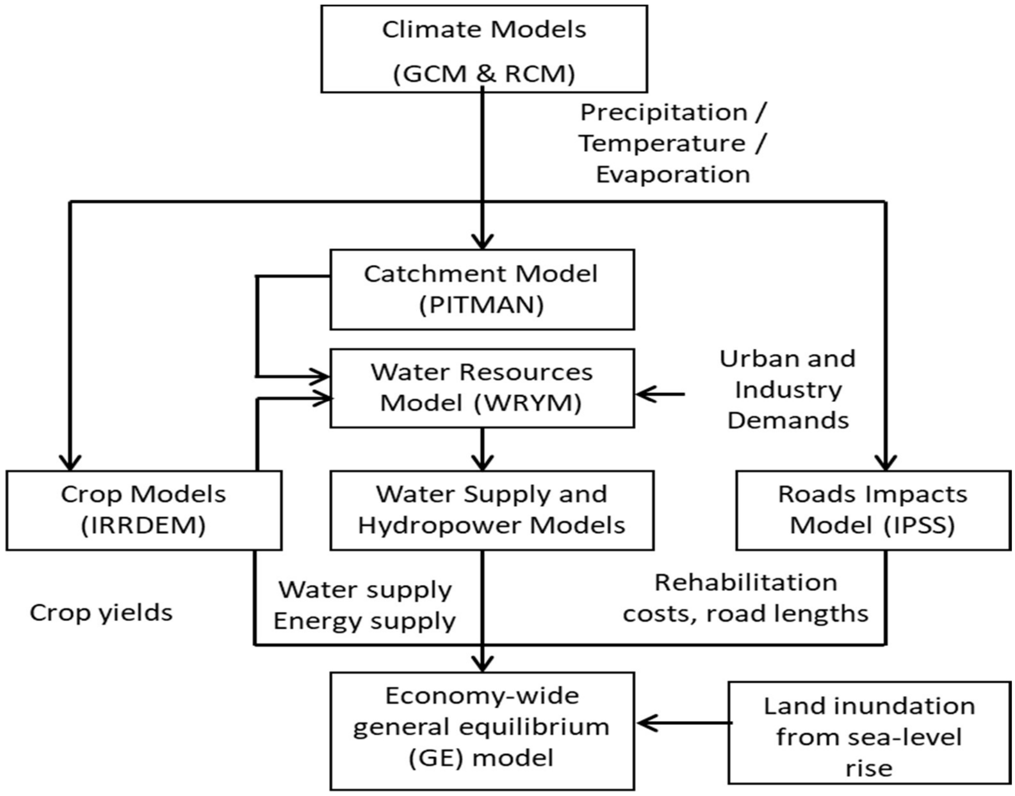
Source: Arndt et al. (2021)

Notes: "C" considers only the 7,200 climates per emissions scenario and reflects the uncertainty about the future climate. "C&W" considers climate and weather together and draws on 720,000 combinations per emissions scenario and reflects both uncertainty about the future and annual variation in the weather. "Scen" is used to mean emissions scenario. "1990" represents the mean of the 1981-2000 period. "2020s" are values for 2021-2029; "2040s" are for 2040-2048; "2060s" are for 2060-2068.

Modelling framework

5.5 To calibrate the economic responses to climate change, several models are employed, accounting for effects on crops, water runoff and availability (including flooding and droughts), and roads (damage from flooding and heat). Figure 11 shows the SACReD modelling system used in the analysis.

Figure 11 SACReD modelling framework



Source: Cullis et al. (2015)

Crop models

5.6 Crop models take input of daily weather, soils, and atmospheric CO2 levels, along with crop management practices such as fertiliser and irrigation application, to produce simulated yield levels. Using large, statistically-representative subsets of the climate ensemble – using 455 out of each 720,000 per emissions scenario – to generate yields for each crop and each location, using an emulator built from the crop model results[17]. This allows a full distribution of yield responses across climate futures accounting for uncertainty and inter-annual variation.

5.7 Table 3 shows the effect of climate change on yields in South Africa. Groundnuts appear to be the crop most adversely affected among the 4, with a potential of a 20% median yield loss between the 2020s and the 2060s across the highest emissions scenario. The most important crop for South Africa in terms of area harvested is maize, which is projected to have a relatively small loss under the lower emissions scenario, but a much higher loss in the higher emissions scenario.

[17] An emulator simplifies the crop model results by regressing monthly climate variables on yields from the crop model and using the regression parameters for generating out-of-sample yields.

Table 3 Yields of key South African crops under climate change, 2C and PF

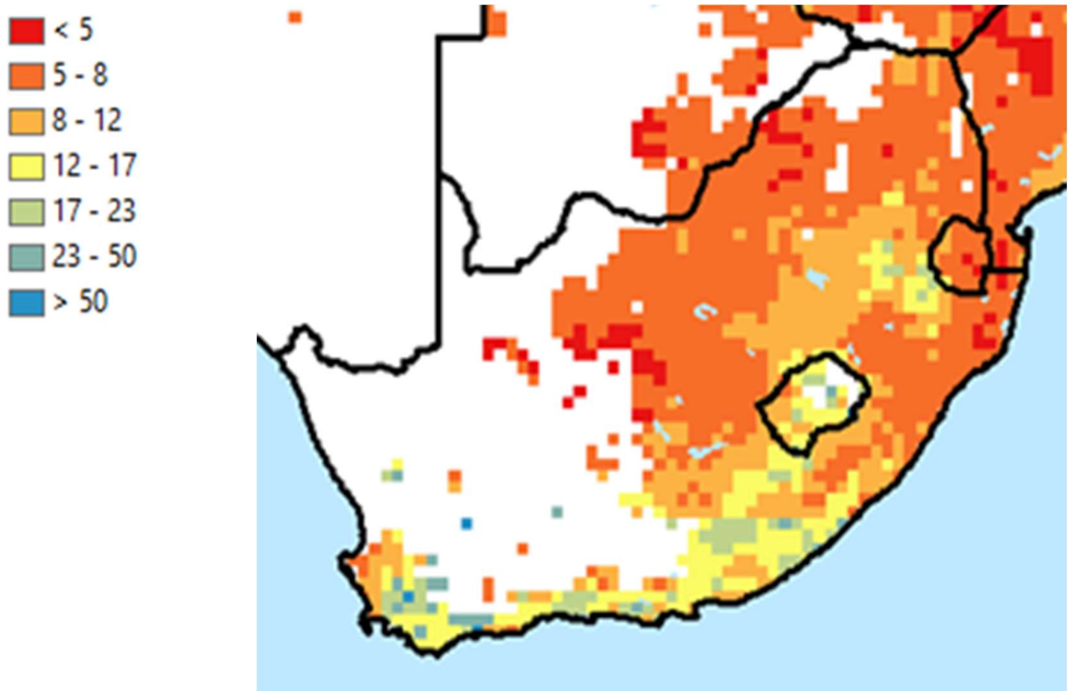
Crop	Change in median yield relative to				Frequency of 1 in 100-year			
	2C		PF		2C		PF	
	2040s	2060s	2040s	2060s	2040s	2060s	2040s	2060s
Maize	0.5%	-2.7%	-1.6%	-7.3%	52	53	35	20
Dry beans	0.3%	-0.7%	-0.2%	-2.6%	61	84	55	59
Soybeans	0.2%	-1.5%	-0.7%	-0.1%	43	54	44	36
Groundnuts	-1.1%	-7.3%	-11.5%	-20.0%	54	53	36	31

Source: Thomas et al. (2021)

5.8 Table 3 also shows the change in frequency of low-yield events, reflecting the shift in the median and the uncertainty. Under the high emissions scenario, a 1-in-100-year low-yield event for maize is projected to occur every 20 years. This shift in frequency for low-yield events is an under-appreciated effect of climate change.

5.9 Figure 12 shows the change in frequency on 1-in-20-year low-yield events for rainfed maize. Noting that southern coastal areas will have a relatively small change compared to the northeast coast and the Vaal River basin northwest of Lesotho.

Figure 12 New frequency of 20-year low-yield events for rainfed maize in 2060s relative to 2020s under a high emissions scenario



Source: Thomas et al. (2021)

Note: A 5 means that what was a 1-in-20-year event in the 2020s would happen every 5 years in the 2060s. For no change in the frequency of a 20-year event, the map would show "20".

5.10 Table 4 shows climate change impact on rainfed maize yields for WMAs for two emissions scenarios and selected decades. The results show that climate change adversely impacts the median yield in Vaal, decreasing it by 11.1% by 2065 in the high-emissions scenario, while increasing it by 11.6% in the southeast coastal area. The range of variation under climate differs, as well. Orange is projected to have 1.07 times the median as a range (5th to 95th percentile) in 2065 under the higher emissions scenario while Western Cape is projected to have a range that is only 0.70 times the median value.

Table 4 Climate impact on rainfed maize yields across WMAs, 2C and PF

Year	Scen	Northeast range		Pongola (NE coast) range		Val range		Orange range		Mzimvubu (SE coast) range		Western Cape range		South Africa range	
		Median	(5-95)	Median	(5-95)	Median	(5-95)	Median	(5-95)	Median	(5-95)	Median	(5-95)	Median	(5-95)
2025	2C	100.1	58.0	108.0	59.1	94.0	68.5	98.5	94.8	106.5	62.0	94.7	63.0	97.9	60.7
2025	PF	100.2	59.8	110.8	58.2	95.2	71.4	103.5	94.1	108.9	60.6	94.7	63.8	98.8	64.4
2045	2C	96.3	65.4	104.9	62.1	91.5	75.2	97.8	98.1	108.3	64.4	97.3	67.5	94.8	69.3
2045	PF	95.1	73.2	108.3	64.8	92.5	79.3	99.2	100.2	113.3	63.4	96.4	67.4	95.9	72.8
2065	2C	98.0	63.1	107.0	61.2	93.2	72.8	97.9	97.7	107.5	61.2	97.3	65.7	96.5	66.3
2065	PF	93.7	74.7	105.0	71.6	88.8	87.7	97.4	106.9	111.6	70.3	97.6	69.9	92.6	78.8

Source: Arndt et al. (2021)

Note: The 1981-2000 period was indexed to be 100 for each hydro-zone and for the nation.

Water models

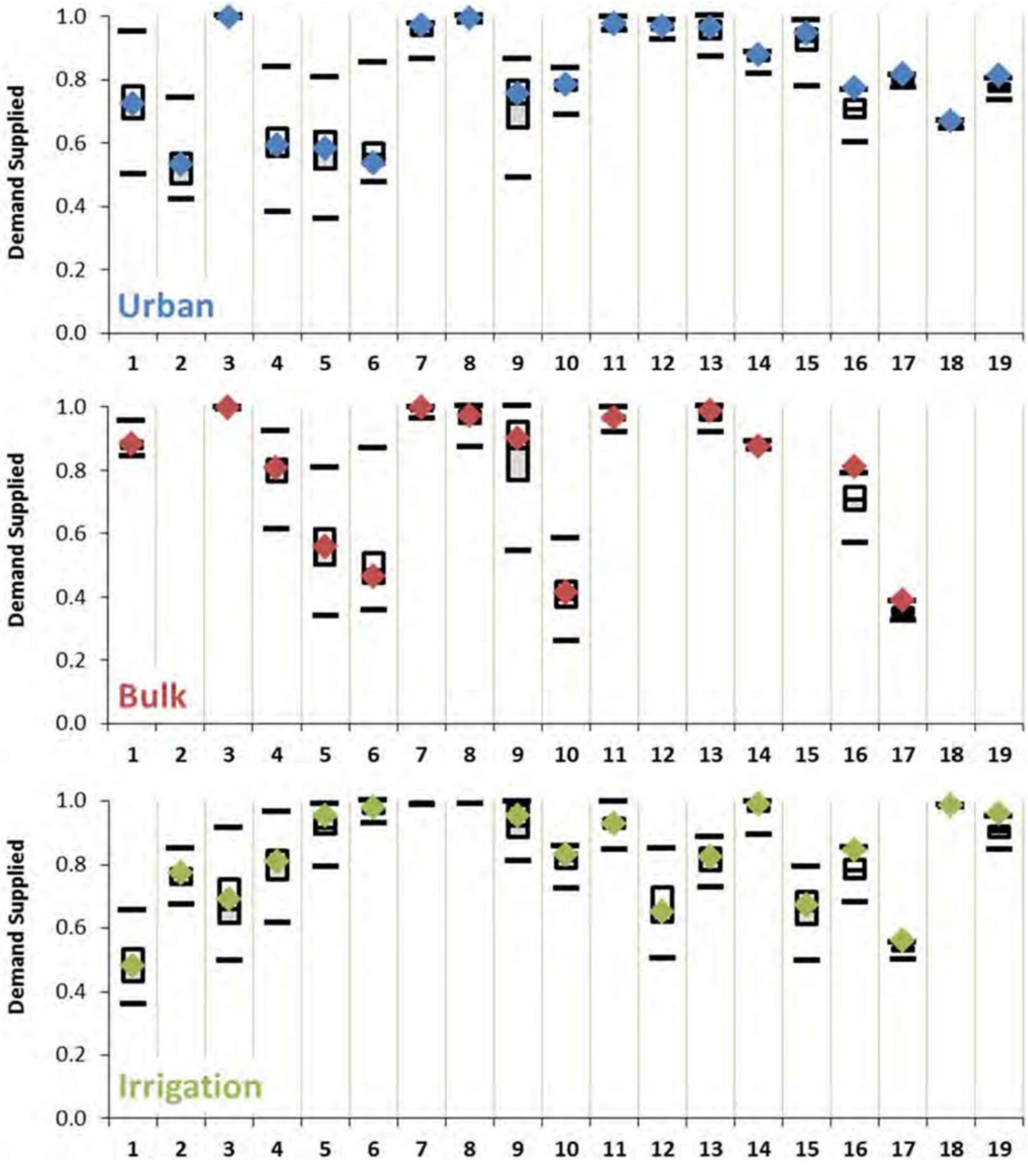
5.11 Note that, from this point forward, we draw from earlier analyses and rely on two scenarios that match with NGFS. To refresh, we have two scenarios: an unconstrained emissions scenario (UCE) that corresponds roughly to current policies and a level one stabilisation scenario (L1S) that corresponds to about 1.5 degrees of warming by mid-century.

5.12 We continue with water models. Water models can assess changes in supply from climate change as well as how well the supply will meet demand. In Figure 13, we see water demand disaggregated into irrigation, urban, and bulk under the UCE scenario. We see that the models project that the median impact under climate change is close to the baseline (pre-climate change) level for most regions, except Western Cape region. We also note that there are risks of significant water shortages in dry scenarios. The analysis only considers the average annual water supply not the impact during critical drought periods.

Road model

5.13 Under climate change, infrastructure will have to endure higher temperatures generally, and experience more frequent and more destructive heatwaves. Increased flooding and higher intensity rainfall events can also cause destruction and more rapid deterioration of infrastructure of all sorts, including roads. Figure 14 shows modelled effects of climate impact on roads under 2 scenarios and compares them with the outcome if adaptation takes place. With no adaptation, annual road maintenance costs increase by R19 billion by 2050. The result is that there will be fewer funds available for other productivity enhancing investments, ultimately negatively impacting sector productivity.

Figure 13 Water availability across zones and sectors under climate change

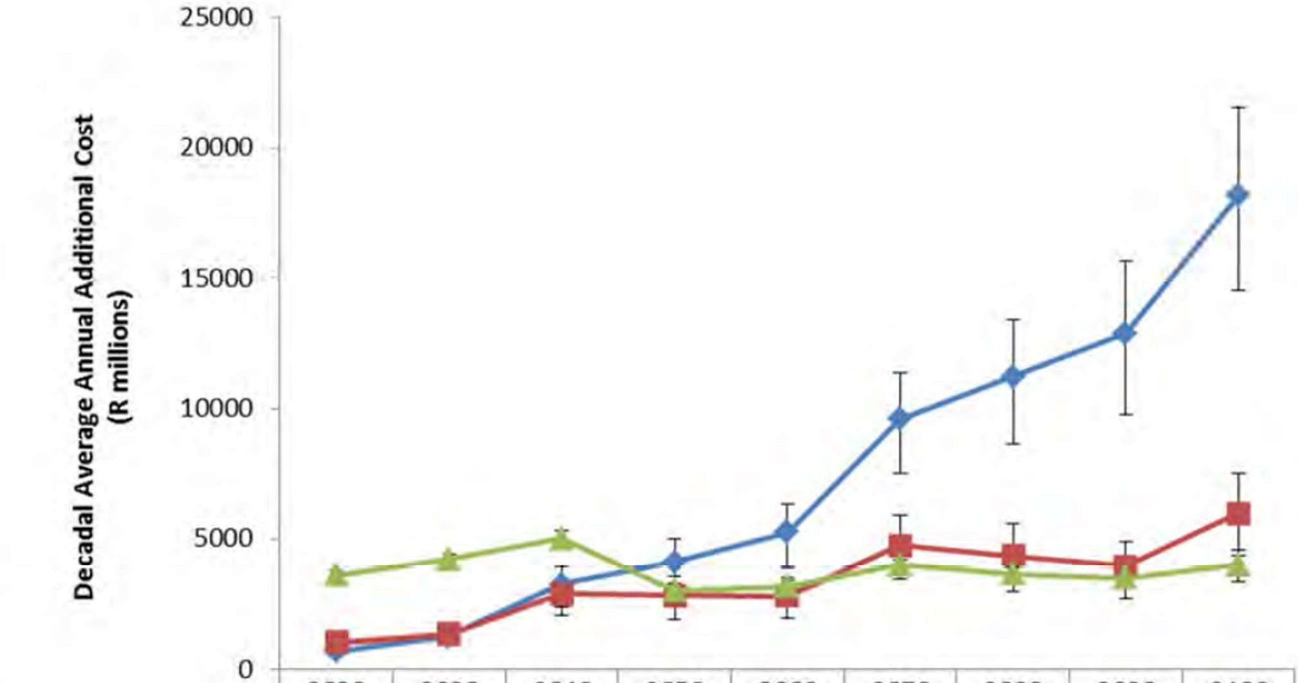


Source: Cullis et al. (2015), X axis is Water Management Areas[18]

Note: Diamonds show the base level. Box and whiskers show the potential impacts under climate change.

[18] Water Management Areas (WMA): 1=Limpopo, 2=Luvhuvhu-Letaba, 3=Crocodile-Marico, 4=Olifants, 5=Inkomati, 6=Usutu-Mhlatuze, 7=Thukela, 8=Upper Vaal, 9=Middle Vaal, 10=Lower Vaal, 11=Mvoti-Umzimkulu, 12=Mzimvubu-Keiskamma, 13=Upper Orange, 14=Lower Orange, 15=Fish-Tsitsikamma, 16=Gouritz, 17=Olifants/Doorn, 18=Breede, 19=Berg

Figure 14 Road maintenance costs under climate change



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

Source: Cullis et al. (2015)

Potential economic impacts

5.14 The biophysical impacts discussed above are passed to an economy-wide model of South Africa with detailed regional and industrial data, particularly on the agriculture sector. The level of detail permits an analysis of direct, indirect, and induced effects of climate impacts, that incorporate market responses to price and supply changes. The model is also able to allow annual adjustments to accumulate over time, and the regional disaggregation permits an additional spatial dimension from which to analyse climate impacts.

5.15 A key assumption is that resources, such as water, capital, and labour, may move freely as it implies that resources can be reallocated quickly and efficiently.

Macroeconomic impact

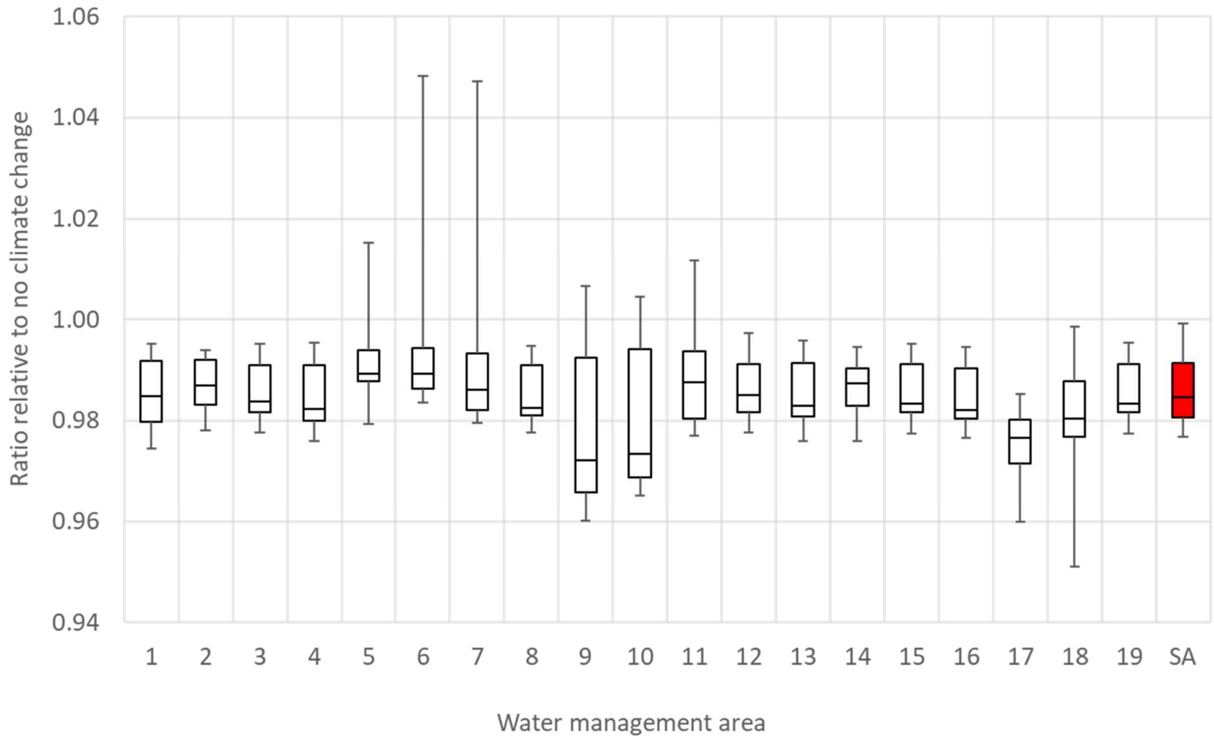
5.16 Figure 15 presents the average impact of climate shocks on the Gross Value Added (GVA) by region, and South Africa as a whole, over 2045-2050, for the UCE scenario. The results are presented as ratio changes to a baseline scenario in which climate change does not occur. Thus, readings below 1 indicate a worse outcome than the baseline.

5.17 Climate change is expected have a negative impact on Gross Domestic Product (GDP) growth, with a median decline of 1.5%. The range of simulated outcomes is between -0.1% and -2.3%. Lower aggregate production is driven mainly by the increase in road infrastructure costs and decline in agricultural crop yields. The impact of climate change on urban and industrial water demand is limited, particularly in large economic centres in Gauteng and KwaZulu-Natal.

5.18 At a regional level, denoted by numeric water management areas, the median GVA impact is expected to be negative across all parts of the country. In the Western Cape – covered in regions 16 to 19 – projections point to especially severe declines in the Olifants and Breede River regions, as the tails of the distributions reach as much as -5%.

5.19 Some regions in Mpumalanga (region 5), KwaZulu-Natal (region 6, 7, and 11), and the Free State (region 9 and 10), show potential for positive outcomes, but these occur in fewer than 25% of climate simulations. These are driven by large uncertainties of sugarcane production, and to a lesser degree, summer cereals and oilseeds.

Figure 15 Regional real GDP estimates, 2045-2050, under UCE expressed as ratio deviations from a no-climate change scenario[19]



Source: Hartley et al. (2021)

[19] Water Management Areas (WMA): 1=Limpopo, 2=Luvhuvhu-Letaba, 3=Crocodile-Marico, 4=Olifants, 5=Inkomati, 6=Usutu-Mhlatuze, 7=Thukela, 8=Upper Vaal, 9=Middle Vaal, 10=Lower Vaal, 11=Mvoti-Umzimkulu, 12=Mzimvubu-Keiskamma, 13=Upper Orange, 14=Lower Orange, 15=Fish-Tsitsikamma, 16=Gouritz, 17=Olifants/Doorn, 18=Breede, 19=Berg

5.20 There is wide uncertainty with respect of agricultural production. Although at the median, GVA is expected to rise by 1.4% compared with a no-climate-change scenario, the range of projected outcomes falls between -7.7% and +37.1%. This is because of uncertainties related to the production of sugarcane and summer cereals, particularly in the east coast of the country.

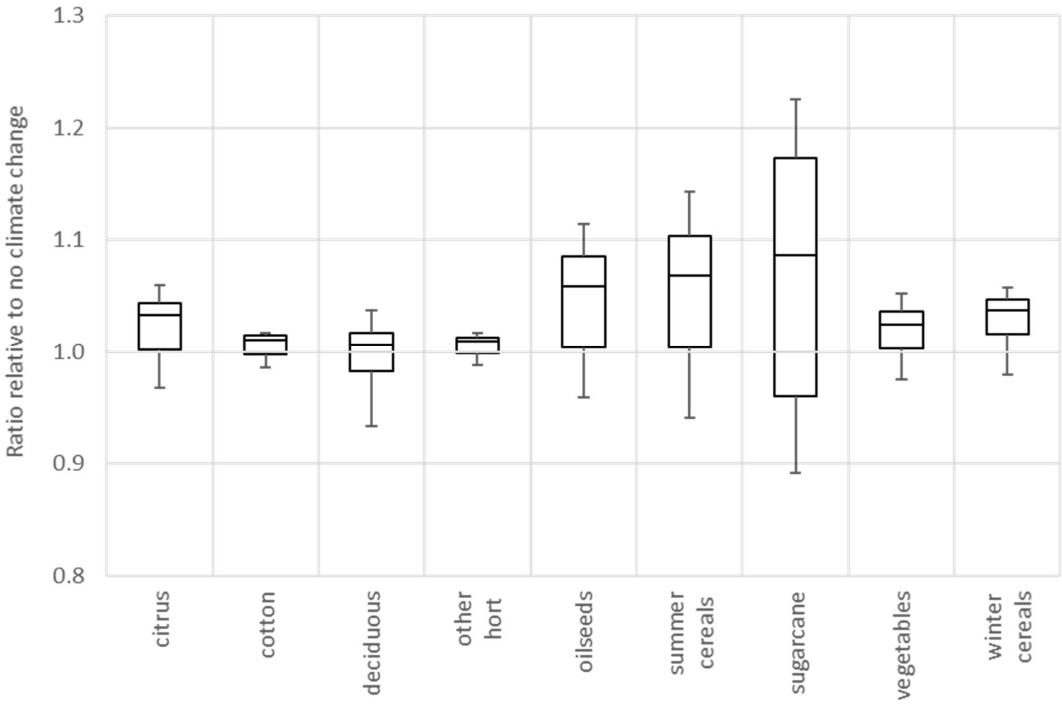
5.21 Climate-induced changes in the agriculture sector have important implications for other sectors of the economy, either through supply linkages that exist, or through a competition for resources in response to changing endowments of water, labour, and capital, and relative prices. The processed food sector is expected to show a larger decline in production than crop agriculture. Other production (aggregated) shows a median decline of 1.7% by the late 2040s, with a range of between -0.6% and -2.3%.

5.22 The weaker production due to climate change contributes to a reduction in household welfare, where lower incomes and higher food prices lead to lower real consumption. As food demand tends to be more inelastic to changes in income and prices, changes in household consumption are expected to affect non-food consumption relatively more, although modelled results indicate that while this effect is present, the median decline in non-food expenditure is only slightly lower than food expenditure.

Impact on agricultural prices, production, and trade

5.23 Lower crop yields raise agricultural prices. Figure 16 shows the expected change in agricultural crop prices compared with a no-climate-change scenario. The largest increases occur for sugarcane, cereals, and oilseeds. This, alongside changes in yields, effects a change in agricultural production that favours more irrigated agriculture to partially offset the decline in rainfed production. Shortfalls in cereal and oilseed demand are met with an increase in imports.

Figure 16 Estimated change in agricultural commodity output prices, 2045-2050, under UCE expressed as ratio deviations from a no-climate change scenario



Source: Hartley et al. (2021)

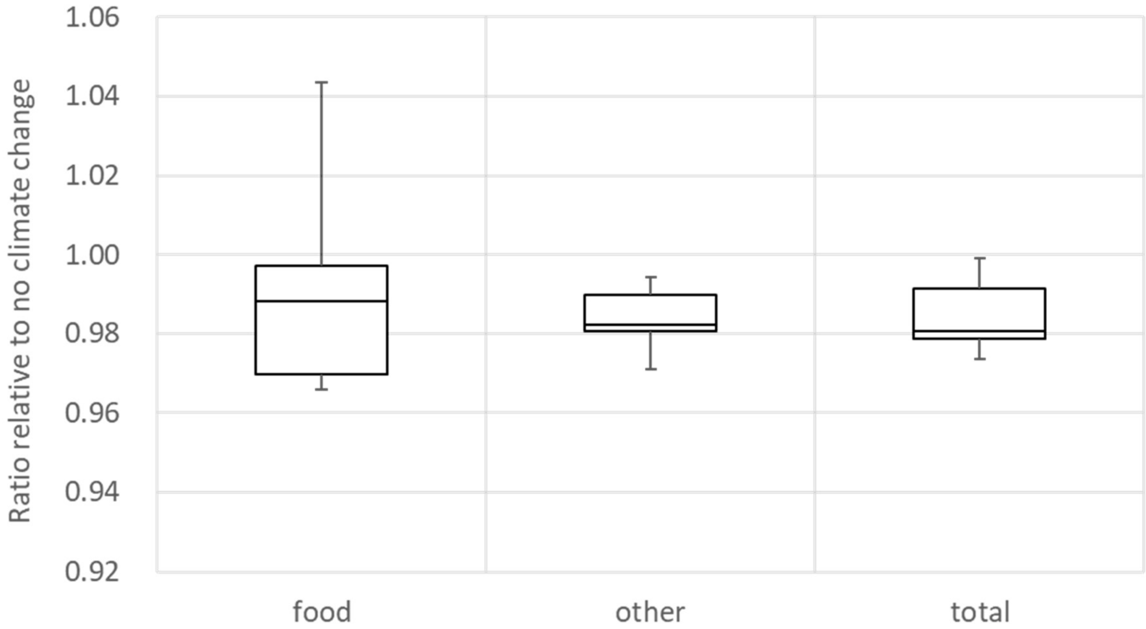
5.24 Despite slightly higher prices for fruit and vegetables, overall production is expected to fall. This is pronounced in the Western Cape, which is a producer of fruit, and where the availability of irrigated water is expected to come under pressure. As fruit and vegetables tend to be more labour-intensive than field crops, lower production under climate change poses a threat to employment in typically rural regions. Further, citrus and deciduous fruits are a major source of agricultural export revenue.

5.25 The combination of higher imports of cereals and oilseeds, and lower exports of fruits, leads to a deterioration of South Africa's food trade balance, and is expected to deepen South Africa's position as a net food importer.

Impacts on household welfare

5.26 Figure 17 shows the effect on household welfare. South Africa is a food secure country but has high levels of household food insecurity. Approximately 20% of households have inadequate and severe inadequate access to food (StatsSA, 2019), concentrated in Northern Cape, Northwest, Eastern Cape, KwaZulu Natal and Mpumalanga. We see that climate change reduces household welfare. Real consumption decreases due to lower incomes and purchasing power. There is also a rise in household vulnerability, and it threatens the availability of food, through its impact on crop yields and the increased need for imports, leading to higher food prices and the reduction of real household income.

Figure 17 Climate impact on household welfare under UCE relative to a no climate change baseline



Source: Hartley et al. (2021)

6. Physical Scenarios: Extreme Events

Drought

6.1 The South African Weather Service defines droughts "on the basis of the degree of dryness in comparison to normal or average amounts of rainfall for a particular area or place and the duration of the dry period. This is what is termed a meteorological drought. Less than 75% of normal rainfall is regarded as a severe meteorological drought but a shortfall of 80% of normal rainfall will cause crop and water shortages which will ultimately affect social and economic factors. Normal rainfall for a particular place is calculated over a 30-year period using for example rainfall figures from 1961 to 1990. Other climatic factors such as high temperature, high wind, low soil moisture and low relative humidity can significantly aggravate the severity of drought conditions and these additional factors should also be considered."[20]

Economic and financial impacts of droughts

6.2 The short-term impact of droughts on private and public capital is generally small, unlike other natural disasters. Droughts, however, have a strong direct

[20] See link: https://www.weathersa.co.za/home/climateques#:~:text=The%20South%20African%20Weather%20Service,is%20termed%20a%20meteorological%20drought

impact on important sectors such as agriculture, energy production and water supply, which generate large spill over effects on the rest of the economy (Freire-González, Decker, and Hall 2017). The size of the impact depends on the severity and frequency (duration) of droughts.

6.3 Large agricultural impacts affect the most vulnerable groups, as these often depend on subsistence farming or employment in the sector (Simbanegavi and Arndt 2014). The impacts relate to the level of precipitation but also to changes in median temperature and the type of soil. Thomas et al. (2021a) show that a temperature range of 29–32 °C and monthly rainfall of 170–240 mm maximises the crop multiplier for maize for most types of soil. Reducing rainfall to 20 mm for one month causes maize yields to drop by 50–60%. Other crops have different temperature and precipitation ranges, but the same exponential relationship to temperatures and rainfall.[21] The impacts are exacerbated by the absence or limited use of crop insurance (IFS 2018). Droughts can also generate long-term impacts by affecting human capital (Hyland and Russ 2019).

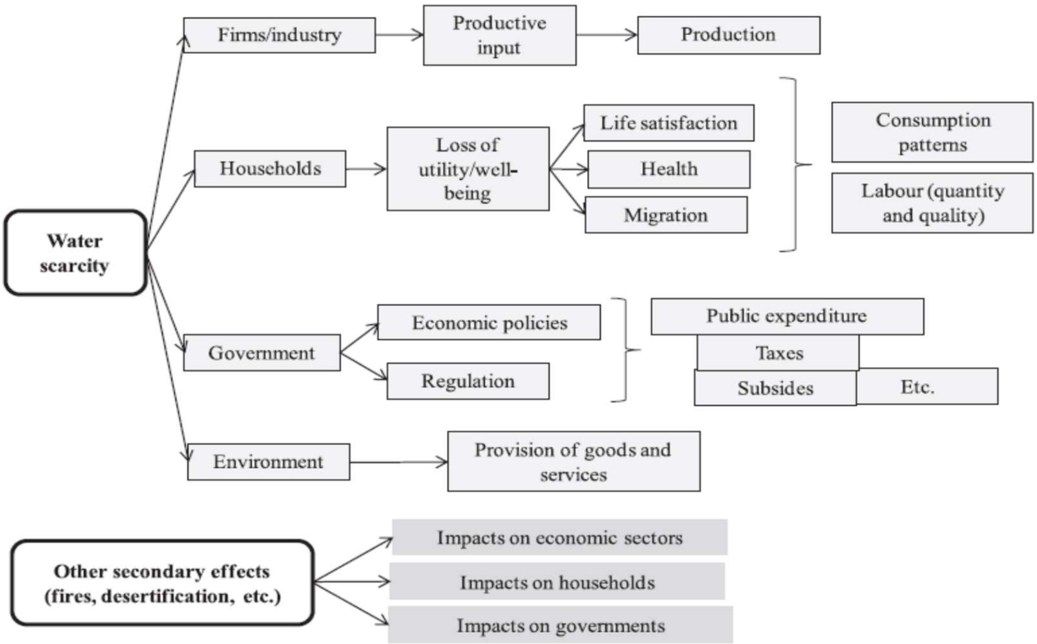
6.4 Droughts are common in Southern Africa, varying in magnitude and frequency, with severe impacts. In South Africa, the 2015/16 drought was declared the worst in 23 years (Baudoin et al. 2017). It was caused by the El Niño weather phenomenon and most affected five provinces (KwaZulu-Natal, Eastern Cape, Northwest, Free State and Northern Cape). It reduced GDP growth by 1.5% and employment by 1.3%.[22] The most severe recorded drought in South Africa was from 1991 to 1992. It reduced normal crop levels by 40% and an estimated 49 000 agriculture-related jobs were lost; national GDP growth fell by 1.5% (Davis and Vincent 2017). Across the Southern African region almost 30 million people were on the brink of famine (Baudoin et al. 2017).

6.5 Figure 18 provides a diagrammatic presentation of how droughts affect the economy. Government policy is an important channel in mitigating but also in amplifying the impacts of droughts. The presence of well managed water storage facilities or ability to move water from less affected drought areas to more affected areas reduce the impacts of droughts and so does an effective disaster risk management strategy (Baudoin et al. 2017; Freire-González, Decker and Hall 2017).

[21] Thomas et al. (2021a) provide detailed crop yield projections for rainfed maize, beans, groundnuts, soybeans, and sorghum under different emission and climate scenarios. They estimate that under the higher emissions scenario, sorghum is likely to have the largest yield reduction, 10% between the 2020s and the 2060s. The maize yield is projected to fall by 8%, the regional losses for beans and groundnuts are expected to be around 6% and for soybeans around 2%.

[22] World Bank Group (2020). FSAP Technical Note – Climate risk and opportunities.

Figure 18 The impacts of droughts



Source: Adapted from Freire-González, Decker, and Hall (2017)

6.6 Drought impacts certain sectors (such as mining, power production, water utilities, agriculture, and tourism) by limiting their ability to service their debt obligations, which in turn affects the banking sector's balance sheet (through asset impairments) and income statement (earnings decline). In addition, the non-performing loans of banks to affected sectors/geographies could increase relative to the same sectors in other provinces.

6.7 Banks also face risks via exposures to government securities. Banks have sizable exposure to domestic government debt (12.6% of total assets).[23] Additional expenditure would be required by the South African government (including municipalities and provincial departments) to implement alternative measures to alleviate the water shortages. This additional burden on the fiscus could affect government's creditworthiness. Additional stress would be through reduced revenue to the government, which depends directly on revenue from the affected sectors.[24] Water Shortages could also affect state-owned enterprises (such as the Land Bank), placing additional financial pressure on the country's government finances.

Climate change and droughts

6.8 As stated above, it is difficult to distinguish between extreme weather events and climate change and to consider these in isolation. Climate change will

[23] As at the end of 2019
[24] Moody's Investors Service (April 1, 2020). Rating Action: Moody's acts on eight South African sub-sovereign issuers.

increase the severity and frequency of droughts, with impacts increasing exponentially as global temperatures rise. The effects, however, are uncertain and differ across spatial zones and seasons.[25] They depend not only on precipitation but also on potential evapotranspiration and climate water balances (Abiodun et al. 2019).[26]

6.9 Abiodun et al. (2019) and Thomas et al. (2021b) provide recent estimates of the impact of climate change on precipitation and droughts under different climate scenarios by linking climate and weather models. Abiodun et al. (2019) define droughts in terms of the standardised precipitation index (SPI) and standardised precipitation evapotranspiration index (SPEI).27 The SPI is widely used to characterise meteorological drought on a range of timescales.[28]

6.10 The SPEI is an extension of SPI and is designed to consider both precipitation and potential evapotranspiration (PET) in determining drought. Thus, unlike the SPI, the SPEI captures the main impact of increased temperatures on water demand. Like the SPI, the SPEI can be calculated on a range of timescales from 1-48 months.

6.11 Once the impacts of evapotranspiration are considered, the intensity and frequency of droughts will increase across the four main water basins in Southern Africa.[29] At global warming of 1.5 °C and below the results on precipitation and droughts is insignificant. At global warming of 3 °C the results become large and significant, implying that more than half of South Africa and Namibia will become hotspots for severe droughts.[30] The Orange River basin is likely to experience the most severe and frequent droughts, but also the most uncertain outcomes.

6.12 While it is clear that higher GHG emissions lead to climate change and increase the probability of extreme events, there is a range of possible outcomes based on various assumptions. Thomas et al. (2021b) account for climate uncertainty and variability by linking emission scenarios to multiple climate and weather models. Their study focuses on the three consecutive wettest months of the

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[25] There are two distinct rainfall seasons in Southern Africa, namely a warm wet season in the summer and a cold dry season in the winter. The region is characterised by arid conditions in the west and a semi-arid climate over much of the central part of Southern Africa to subtropical humid conditions over the low-lying regions to the east and the north, and a Mediterranean climate in the southwestern portion of South Africa (Davis and Vincent 2017).

[26] Potential evapotranspiration is defined as the amount of evaporation that would occur if sufficient water sources were available. The climate water balance is the difference between precipitation and potential evapotranspiration.

27 The SPI calculates the drought index based on precipitation only, while SPEI uses climatic water balances. (www.weathersa.co.za)

[28] On short timescales, the SPI is closely related to soil moisture, while at longer ones it can be related to groundwater and reservoir storage. The SPI can be compared across regions with markedly different climates. It quantifies observed precipitation as a standardised departure from a selected probability distribution function that models the raw precipitation data.

[29] The four main water basins are those of the Zambezi, Orange, Okavango and Limpopo rivers.

[30] Maúre et al. (2018) study the impact of climate change on precipitation. Higher temperature changes have higher impact on precipitations. The area most affected is the Western part of South Africa.

year, as these are most important for crop production and are also a good proxy for annual rainfall levels. The results indicate that Angola, Botswana, Namibia, and Eswatini are more likely to experience extreme wet conditions due to climate change, while Mozambique, Malawi, Zambia, Lesotho, South Africa, and Zimbabwe are more likely to experience extreme dry conditions favouring bigger dry extremes. While median precipitations levels remain largely unchanged due to climate change, the variability increases significantly and with that the severity and intensity of extreme droughts or floods. The study suggests that severe droughts, expected to occur with probability of 1% each year or one in every 100 years, are likely to take place every 42 years by 2060 in South Africa if median temperatures increase by more than 2 °C. Extreme heat events will be even more common, taking place every two years.

Drought scenario: 1 in 100-year event

6.13 Using the framework of Thomas et al. (2021a) and assuming the Paris Forever scenario,[31] a drought scenario similar to the extreme 1991-1992 drought, which was of the 1-in-100-years type, is developed. As indicated before, this drought reduced normal crop yield by 40%. The cumulative distribution function for rainfall of this scenario is presented in Figure 19. The scenario shows 8.4% lower rainfall than a 1-in-100-years event in the 2000s and almost 30% lower rainfall than the median in the 2000s.[32]The reduction in rainfall is over a period of two years.[33] It is recommended that financial institutions, including insurers, stress test their agricultural exposures[34] to at least a 1-in-100-year event with a reduced yield of 40% and also with a 30% reduction in yield as a sensitivity test.

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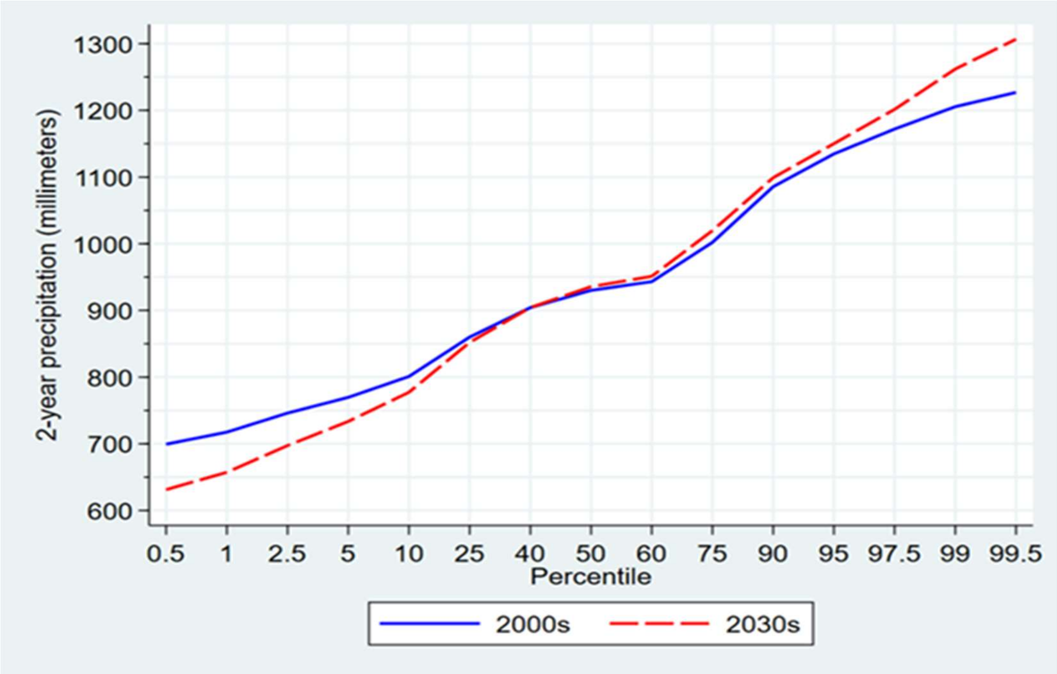
[31] The Paris Forever scenario is carbon price-adjusted based on the different stringency of countries' nationally determined contributions. Countries adhere to NDCs beyond 2030.

[32] We choose to use rainfall, as the other measures (SPEI and SPI) require that we also specify the soil type. The rainfall measure is simpler to use and communicate.

[33] The scenario is generated as following. We started with the assumption of the Paris Forever emissions scenario. From that scenario, 7 200 possible climate futures were generated. Each was then overlaid with 100 randomly drawn, de-trended historical weathers, each of which spanned 70 years. (Note: each year was randomly drawn, not the 70-year sequence.) Then precipitation was calculated for five separate two-year periods, 2001–2010, and five separate two-year periods, 2031–2040. The distribution of those draws (aggregated to the national level from the pixel level) – each having 3.6 million observations – for each two-year period were calculated. We compared the distribution from the 2001–2010 period to the distribution of the 2031–2040 period, from which we found that a 1-in-100-years event in the 2000s would occur every 27 years in the 2030s. Or, equivalently, a 1-in-100-years event in the 2030s would have 8.4% less rainfall than an equivalent event in the 2000s.

[34] Given that droughts and climate have the largest impact on agriculture, the focus here has been on the agriculture sector. Future work can consider the impacts of droughts more broadly. In terms of the economy-wide impacts, while the channel linking economic impacts to droughts is agriculture, the model does assess the value chain impacts from this which would include manufacturing.

Figure 19 Cumulative distribution function plot: Rainfall



Source: Thomas et al. (2021a)

Floods

6.14 Floods are often caused in coastal areas by high tides, storm surges and strong winds that form high-energy waves. Harvey (2007) identified three types of urban floods: rapid-onset, slow-onset, and annual seasonal flooding. Rapid-onset floods include flash floods, tidal surges, floods provoked by cyclones or those accompanied by strong winds, high runoff from heavy rainfall, dam bursts and overtopping, and canals and rivers bursting their banks. Slow-onset floods are produced by prolonged rainfall that causes low-lying areas to gradually become flooded over a period of a few days or weeks. Both coastal and inland flooding can occur together when the same storm drives coastal flooding and inland flooding and the two combine in estuarine environments.

Economic and financial impacts

6.15 Similar to droughts, floods can generate large economic and financial costs. The immediate impact of flooding is the loss of human life, damage to property, destruction of crops, loss of livestock, the non-functioning of certain industries, and the deterioration of health conditions. Furthermore, floods hamper economic growth and development owing to the high cost of relief and recovery. This will negatively affect investment in infrastructure as well as other development activities, which may cripple a developing economy such as South Africa’s. Moreover, recurrent flooding discourages long-term investment by both the private and public sectors, devastating economic growth prospects.

6.16 Insurance is an effective tool to mitigate against extreme flooding. Melecky and Raddatz (2016), using data from high- and middle-income countries between 1975 and 2008, found that countries with lower insurance coverage and strained fiscal balances experience larger economic costs due to flooding compared to countries with high insurance coverage. Insured losses have no statistically significant impact on long-term GDP while uninsured losses result in cumulative output costs over ten years or more (Von Peter, von Dahlen and Saxena (2016)). Insurance can reduce the economic disruption caused by floods as payments are disbursed quicker than government assistance (Kousky and Shabman, 2015, cited in OECD, 2016).

6.17 However, there are challenges with insuring flood risks. According to the Swiss Reinsurance company Ltd (2012), certain criteria must be met before insurance can be offered for a certain risk. First, the risk must be quantifiable. Second, a large community with assets at risk must be established to mutually share the risk, allowing for diversification through risk-pooling. Last, the risk must occur randomly. Insurance companies must be able to collect enough insurance premiums to cover the losses of communities. The Insurance Bureau of Canada's examination of the factors that affect the insurability of flood risk established that flood risk does not adequately adhere to the economics of insurance, given that flood insurance leads to adverse selection which hampers diversification through risk pooling. Additionally, flood losses are attributable to underinvestment in public infrastructure and poor land-use planning. Thus, unless governments improve their planning to mitigate flood risks, the overall availability of flood risk insurance may remain commercially unfeasible. Importantly, unless there are effective flood maps available for the assessment of flood hazards by insurers, the financial management of flood risks will remain a challenge.35

Climate change and floods

6.18 South Africa has a known history of floods ranging from minor local events to national disasters. Often widespread flooding is caused by acute events such as cut-off lows and cyclones, such as cyclone Dineo in February 2017 (Davis-Reddy and Vincent, 2017). Along the coast, flooding is mainly triggered by high tides, storm surges and high-energy waves. Inland floods are generated in several ways, including powerful, short-duration rainfall that saturates rapidly or

[35] Accurate flood risk maps are those that provide reliable information to insurers on the potential consequences of flood on structures located in inundation zones. Furthermore, they are vital when estimating the frequency of floods, the assessment of the impact of floods on infrastructure, and the pricing of risk premiums. A study conducted by the University of Stellenbosch concluded that in South Africa there needs to be more current and accurate data because floods are becoming a recurrent phenomenon (Els and Van Niekerk, 2013). The study further established that the capturing of flood data in South Africa is very limited. Above all, South Africa has no single agreed upon method to assess the magnitudes and frequency of floods. Moreover, all-inclusive approaches based on estimating flood durations and flood lines are impractical due to the unavailability of data and the time and resources these would require the absence of high-quality maps is a noteworthy impediment to the effective financial management of flood risks as well as to insurance coverage.

exceeds the ability of the soil to absorb excess water, causing flash floods. Floods can also be produced by less extreme rainfall, or even a sequence of events that saturate catchments causing long duration floods (Musungu et al., 2012, cited in Le Maitre & Kotzee,2019). South Africa experienced 77 major floods between 1980 and 2010, which cost the lives of at least 1,068 people. Since 2010, many severe floods have resulted in the loss of life, livelihoods, and damage to property (Le Maitre et al., 2019). The KwaZulu Natal floods in 2022 led to extreme damage of infrastructure with 460 people losing their lives.

6.19 A study conducted by the Council for Scientific and Industrial Research (CSIR), based on global climate outputs, compared the degree of change in rainfall extremes in the future with current rain fall. The study observed that between 2021 and 2050 daily rainfall will increase in many parts of the country, predominantly over the Highveld and northern Drakensberg, and along the south-eastern and eastern coasts. However, western and south-western areas are likely to experience reduced rainfall. This is in line with the anticipation that ever-increasing temperatures will increase the intensity of rainfall (Dedekind et al. 2016, cited in Le Maitre & Kotzee,2019). The same pattern is evident in the far future (2070–2099), with increases in rainfall in the central, eastern and northern parts of the country, and reductions in the west and south-western parts.

The spatial and temporal nature of floods

6.20 South Africa faces three major types of flooding:

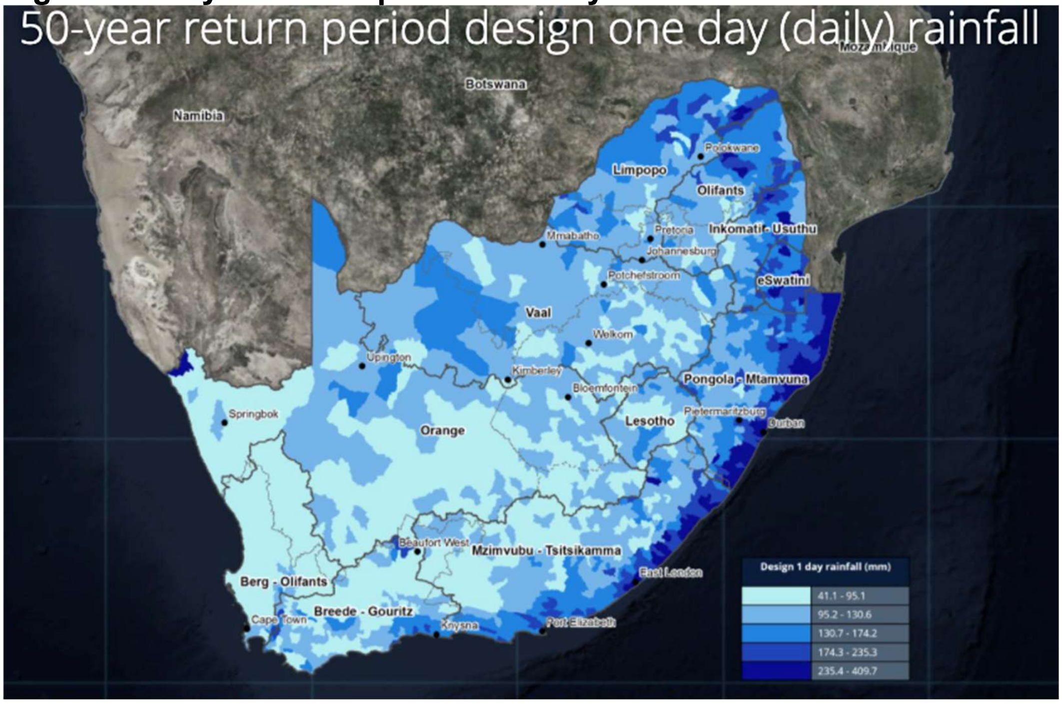
1) River or fluvial flooding: Heavy rain over causes rivers to leave their banks and inundate their flood plains.
2) Urban or pluvial flooding: Periods of rain overwhelm urban drainage systems leading to localised flooding
3) Coastal flooding: Storm surge, waves and high tides and estuary rain induce flooding alone or in any combination, leading to coastal flooding.

6.21 The timescales of precipitation events are different for each of these flooding types, and the impact of climate change on these meteorological processes are different. In South Africa, urban flooding is driven by daily rainfall events, thunderstorms and intense daily rainfall during storms; river flooding results from multi-day to weekly events such as persistent cut off-lows, midlatitude cyclones and cold fronts; while coastal flooding is caused by persistent cut off-lows, midlatitude cyclones, cold fronts and intense storms.

6.22 The nature of the flooding threat is highly variable across the landscape of South Africa, with urban flooding in the regions with large impervious landscapes due to development, and coastal flooding only in the coastal zone, while river flooding can occur in any flood plain – sometimes far downstream of the rain event.

6.23 Figure 20 shows the spatial variability of the 50-year daily design storm, or the daily rainfall expected with a 2% probability each year.

Figure 20 50-year return period one day rainfall



Source: Schulze, et al. 2008

Flood scenario

6.24 When assessing the impact of climate change, extreme precipitation and flooding and the potential social and economic damages, two approaches are used: an expected value approach, and Monte-Carlo time series approach.

6.25 Civil infrastructure (roads, bridges, levees, etc) is designed with climate variability and risk in mind. Engineers build the infrastructure to withstand a storm of a certain magnitude associated with a probability of occurrence or return period.[36] For South Africa, the design standard for flood infrastructure is the 50-year storm estimate by analysing historic precipitation data. It is assumed that there will be little to no damage if precipitation lower than that amount occurs and that there are damages even with no climate change. Climate change raises concerns that changes in the meteorological or weather process will change the probability distribution of extreme rainfall events. Therefore, the infrastructure is no longer able protecting to the acceptable risk of 2%, as the chance of surpassing these levels is 5% or 10%.

6.26 Climate science has developed tools to estimate the climate change impact on the probability distribution of extreme rainfall events from GCM models. An expected value approach is best suited for infrastructure that uses a design

[36]Return Period equals 1 over probability of occurrence; T = 1/P. Hence, a 10-year storm has a 10% probability of occurring each year and a 2-year storm has a 50% probability of occurring each year.

storm approach to design and is localised and not dependent on large spatial correlations over river basins, such as urban drainage and transportation systems.

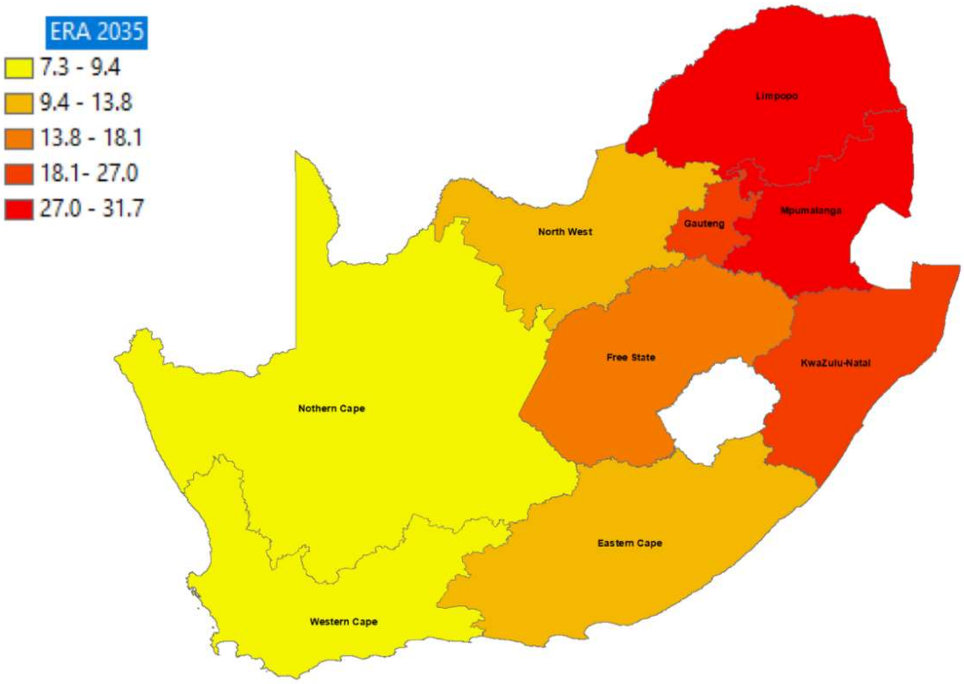
6.27 Using the framework of Thomas et al. (2021a) and assuming the Paris Forever scenario[37] time series of daily precipitation are developed. These series will be sampled to select the maximum weekly extreme precipitation events for each year. These events will be run through large-scale daily hydrologic models of the 148 secondary catchments of South Africa. Damages will be based on actual storm events from river flooding within the catchments. Given the large number of times series generated, we should generate some very large low-frequency events, but possibly not any very low-frequency events (e.g., 500- or 1000-year return period events).

6.28 South Africa has established the 50-year- 24-hour rainfall as the flood protection design standard for most infrastructure capital. A 50-year flood has a 2.0% chance of occurring in any year, a 45.5% chance over the next 30 years, and a 63.6% chance over the next 50 years. Designing infrastructure to withstand the 50-year storm does not involve an expectation that there will be no damage; rather, the design standard aims for limited damage. Typically, damages worsen rapidly as the event magnitude exceeds the design standard. So, for example, a bridge designed for a 50-year storm that faces a 100-year storm will, on average, experience damage of 55% of its value in addition to the disruption to the local economy and society.

6.29 An analysis has been performed on the change in 24-hour storm intensities for South Africa using 30 Global Circulation Models (GCMs) for the Representative Concentration Pathway (RCP) 8.5 emission scenario. Analysis focuses around “eras”, meaning a time period in the future. These projections have been spatially averaged over the nine provinces of South Africa and, together with a capital damage function calibrated to available data for South Africa, the increase in capital damage for capital in the provincial flood plains was estimated. Results are given in Table 5 for three eras and in Figures 21 and 22 for eras corresponding to 2035 and 2050 respectively.

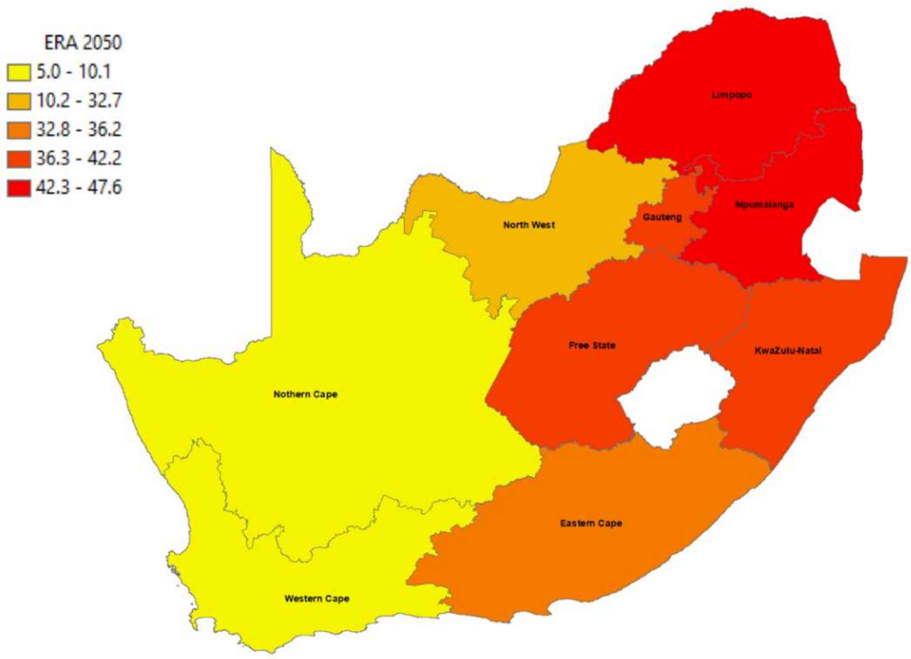
[37] The Paris Forever scenario is carbon-price-adjusted based on the different stringency of countries’ nationally determined contributions (NDC). Countries adhere to NDCs beyond 2030.

Figure 21 Increase in percentage capital flood damage for the projected 50-year storm of 2035 on infrastructure designed for such a storm.



Source: Strzepek, 2022

Figure 22 Increase in percentage capital flood damage for the projected 50-year storm of 2050 on infrastructure designed for such a storm.



Source: Strzepek, 2022

Table 5 Increase in percentage capital flood damage for the projected 50-year storm for eras 2035, 2050 and 2085, on infrastructure designed for such a storm.

	2035	2050	2085
Western Cape	9	5	20
Eastern Cape	14	36	49
Northern Cape	7	10	40
Free State	18	40	49
KwaZulu-Natal	27	42	49
North West	12	33	49
Gauteng	24	41	49
Mpumalanga	30	45	49
Limpopo	32	48	49

Source: Strzepek, 2022

6.30 The results presented in Table 5 show a significant increase in percentage capital damage of the increasing intensities of the 50-year storm, if no adaptation is made to existing infrastructure or new infrastructure is still designed to meet the historic 50-year storm. Of course, not all infrastructure capital is in the flood plain (though most river bridges inevitably are). For example, a recent analysis of Rwanda found that 12% of agricultural and mining capital and 11% of manufacturing, services and government capital are located in the flood plain of the 50-year flood.

6.31 To understand the potential impact to South Africa of increased flood damage, a projection of the loss of economic value due to flood damages was estimated at a provincial level. Value of agricultural and mining capital and manufacturing, services and government capital was obtained by province from SARB for 2020. Assuming a 3% annual growth in capital and using the percentages of each type of capital in the flood plain and the increased damages from Table 5, the total expected capital asset losses in each province in 2015 Rand was estimated. The results are presented in Table 6.

Table 6 Capital flood losses for the projected increasing 50-year storm for eras 2035, 2050 and 2085 on infrastructure design for the historic 50-year storm (R millions)

	Agriculture and mining				Manufacturing, services, and government			
	2020	2035	2050	2085	2020	2035	2050	2085
Western Cape	721	1 981	2 026	6 108	12 392	34 063	34 839	105 016
Eastern Cape	160	537	1 350	2 685	6 429	21 604	54 289	107 973
Northern Cape	848	2 095	3 164	11 992	1 461	3 608	5 449	20 652
Free State	1 635	6 456	14 779	27 501	4 063	16 040	36 722	68 332
KwaZulu-Natal	1 351	7 003	12 867	22 722	14 367	74 493	136 878	241 719
North West	1 961	6 178	15 298	32 701	3 667	11 555	28 612	61 160
Gauteng	1 112	5 321	10 270	18 645	30 324	145 122	280 115	508 523
Mpumalanga	1 950	10 766	19 503	32 794	5 591	30 875	55 933	94 049
Limpopo	2 396	13 974	25 167	40 316	4 814	28 071	50 557	80 988
TOTAL RSA	12 133	54 311	104 426	195 464	83 108	365 432	683 393	1 288 413

Source: Strzepek, 2022

7. Conclusion and next steps

7.1 Climate related risks will have large economic, social and financial impacts. The magnitudes and timing of these impacts are uncertain. Scenario analysis provides a useful tool to deal with uncertainty and understand the likely impacts. This report is intended to provide the first set of benchmark scenarios to be considered by financial institutions operating in South Africa.

7.2 The output from the scenarios focuses on the real impacts on the economy. Future work will aim to relate these to outputs using the NiGEM model. This will provide additional impacts for financial related outcomes and further analysis will be conducted to understand how these outcomes impact the financial sector.

7.3 These scenarios are intended as a tool for all banks, insurers and other firms to use as part of their internal climate risk analysis, disclosures and risk management. These scenarios reference local data and modelling, which provide best available data and models for South Africa. These are deemed most applicable for firms to use in climate related risk scenarios to better understand their exposure to climate risks and to internalise these risks as appropriate to their situation. These scenarios are based on work done in South Africa to date, under the guidance of a working group. These scenarios are 'open access' products and are not a mandated tool of the SARB or financial regulators but may inform future policy and regulatory actions within their mandate.

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Appendix A: Mitigation risks – Reference case scenario select assumptions and outputs

Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Population (thousands)	61381	62088	62803	65956	68819	71375	73620	75518
Coal exports (tons)	65.6	62.4	59.3	43.5	43.5	43.5	32.6	21.7
Real GDP by sector (Rbn)								
Total	3222	3294	3368	3728	4271	4934	5761	6812
Agriculture	79	80	82	91	102	112	123	137
Coal mining	55	54	53	45	40	37	30	23
Other mining	220	224	229	259	293	328	366	416
Food and beverages	110	113	116	130	147	163	182	204
Pulp and paper	20	20	21	23	26	29	34	40
Chemicals	54	55	55	58	48	46	50	57
Petroleum	22	22	21	5	3	2	1	1
Non-metallic minerals	16	16	16	18	21	24	28	33
Iron and steel	14	14	14	16	17	19	22	25
Non-ferrous metals	10	10	10	15	22	30	37	46
Other industry	324	331	339	374	425	485	556	650
Transport	198	203	208	234	280	348	434	547
Commerce	2100	2152	2204	2460	2847	3311	3898	4633
Employment by sector (thousands)								
Total	10607	10899	11184	12364	13971	15915	18351	21275
Agriculture	834	855	875	963	1060	1121	1234	1344
Coal mining	59	58	57	48	43	40	32	25
Other mining	335	342	351	398	440	474	527	617
Food and beverages	522	536	549	606	670	721	792	868
Pulp and paper	70	72	74	80	89	99	113	129
Chemicals	207	211	214	227	204	203	222	252
Petroleum	33	33	32	8	4	3	1	1
Non-metallic minerals	142	146	150	163	184	208	239	276
Iron and steel	147	150	153	167	184	199	221	247
Non-ferrous metals	25	26	29	47	69	79	97	116
Other industry	1853	1901	1949	2133	2385	2655	3018	3458
Transport	733	754	774	880	1040	1330	1631	2027
Commerce	5647	5815	5977	6644	7599	8783	10224	11915
Real household consumption (Rbn)	2316	2375	2435	2715	3153	3678	4288	5024
Prices								
Electricity (2019 R/kWh)	1.42	1.44	1.43	1.41	1.41	1.46	1.53	1.48
Implied carbon price (2019 R/ton)	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0
Power sector investment (2019 Rbn)	120	130	144	436	662	1025	1481	1820

Appendix B: Mitigation risks - 7GT (Net Zero Carbon Emissions by 2050) select outputs, percent difference relative to Reference case unless else specified

Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Real GDP by sector								
Total	-0.7	-1.1	-1.8	-3.5	-3.8	-4.4	-4.5	-8.2
Agriculture	*-1.3*	*-1.3*	*-1.2*	*-2.2*	*-2.0*	*-0.9*	*-0.8*	*-4.4*
Coal mining	*-1.8*	*-5.6*	*-7.5*	*-20.0*	*-25.0*	*-32.4*	*-36.7*	*-52.2*
Other mining	*-0.5*	*-0.9*	*-1.3*	*-3.9*	*-5.5*	*-6.1*	*-7.4*	*-15.4*
Food and beverages	*-0.9*	*-0.9*	*-1.7*	*-3.1*	*-2.7*	*-1.8*	*-2.2*	*-5.9*
Pulp and paper	*0.0*	*0.0*	*-4.8*	*-4.3*	*-3.8*	*-3.4*	*-5.9*	*-10.0*
Chemicals	*0.0*	*0.0*	*0.0*	*-1.7*	*-2.1*	*-19.6*	*-14.0*	*-15.8*
Petroleum	*0.0*	*0.0*	*0.0*	*40.0*	*33.3*	*-50.0*	*0.0*	*0.0*
Non-metallic minerals	*0.0*	*0.0*	*0.0*	*0.0*	*-4.8*	*-4.2*	*-7.1*	*-12.1*
Iron and steel	*0.0*	*0.0*	*0.0*	*-6.3*	*-5.9*	*-5.3*	*-9.1*	*-12.0*
Non-ferrous metals	*-10.0*	*0.0*	*0.0*	*-13.3*	*-22.7*	*-23.3*	*-29.7*	*-39.1*
Other industry	*-0.6*	*-0.9*	*-2.7*	*-2.7*	*-1.6*	*-1.4*	*-0.5*	*2.9*
Transport	*-1.0*	*-2.0*	*-1.4*	*-3.4*	*-3.9*	*-4.3*	*-4.8*	*-11.7*
Commerce	*-0.6*	*-1.0*	*-1.7*	*-3.5*	*-3.6*	*-4.2*	*-4.4*	*-8.2*
Employment by sector								
Total	-0.2	-0.5	-1.2	-2.6	-2.8	-3.8	-3.8	-5.8
Agriculture	0.0	-0.1	-0.9	-1.2	-0.8	-0.1	-0.2	0.1
Coal mining	-1.7	-3.4	-7.0	-18.8	-25.6	-32.5	-37.5	-52.0
Other mining	-0.3	-0.3	0.0	-3.3	-4.5	-6.1	-7.2	-18.5
Food and beverages	-0.2	-0.4	-0.5	-1.7	-1.2	-1.1	-1.4	-2.9
Pulp and paper	0.0	-1.4	-1.4	-2.5	-3.4	-5.1	-3.5	-3.9
Chemicals	0.0	-0.9	-0.9	-2.2	-2.5	-13.8	-10.4	-12.3
Petroleum	0.0	0.0	0.0	25.0	50.0	-66.7	0.0	0.0
Non-metallic minerals	0.0	0.0	-1.3	-1.8	-2.7	-5.3	-5.9	-9.8
Iron and steel	-0.7	-1.3	-2.0	-3.6	-5.4	-6.0	-8.1	-12.1
Non-ferrous metals	-4.0	0.0	-6.9	-14.9	-24.6	-22.8	-32.0	-41.4
Other industry	-0.2	-0.5	-1.0	-1.6	-1.6	-2.5	-2.4	-3.0
Transport	-0.3	-0.7	-1.0	-3.1	-3.5	-3.8	-4.4	-9.1
Commerce	-0.3	-0.5	-1.3	-2.8	-3.1	-4.1	-3.9	-5.5
Real household consumption	-0.7	-1.1	-2.8	-2.9	-2.7	-3.1	-2.8	-6.4
Prices								
Electricity (2019 R/kWh)	2.3	4.3	7.7	16.8	17.5	16.4	12.2	7.5
Implied carbon price (2019 R/ton)	287	308	331	479	697	1057	1493	12102
Power sector investment (2019 Rbn)	100.0	139.2	185.4	128.0	98.6	72.2	55.0	95.0

Appendix C: Physical risks - No climate change assumptions and outputs (index 2023=100)

The growth assumptions are based on conditions at the time of model runs (2013/2014). Since then, the underlying growth conditions in South Africa has changed. The impacts of climate change (Appendix D) can be applied to updated growth baseline as the data represents the difference relative to a no climate change case.

Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Prices								
Crude oil (per barrel)	100.0	103.0	106.0	115.9	125.2	130.7	137.4	143.7
Natural gas (per Tcf)	100.0	102.5	104.9	120.9	139.8	162.1	192.0	230.0
Coal (per ton)	100.0	100.6	101.3	104.4	107.7	111.0	114.3	118.2
Agriculture	100.0	100.6	101.3	103.9	106.8	109.6	112.4	115.8
Real GDP by sector								
Total	100.0	104.5	109.2	136.7	172.1	217.5	275.9	334.6
Summer cereals	100.0	104.0	108.2	132.8	164.1	204.6	256.5	308.7
Winter cereals	100.0	103.5	107.1	128.3	153.9	187.7	229.1	270.4
Citrus fruit	100.0	102.1	104.3	120.2	141.9	173.1	212.6	253.0
Deciduous fruit	100.0	101.8	103.5	115.7	131.1	152.8	179.7	206.6
Oils and fats	100.0	103.2	106.5	125.6	148.7	178.4	214.8	250.7
Cotton	100.0	103.8	107.7	130.4	158.4	194.2	239.0	283.5
Sugarcane	100.0	104.7	109.6	138.1	174.5	221.0	281.1	341.6
Vegetables	100.0	104.1	108.4	132.1	161.3	196.2	239.8	281.9
Other horticulture	100.0	103.4	106.8	127.1	152.3	184.9	225.4	265.5
Other agriculture	100.0	103.9	108.0	132.1	162.9	203.0	254.2	305.7
Mining	100.0	104.8	109.8	139.1	176.8	226.0	289.4	353.9
Food and beverages	100.0	104.3	108.9	135.6	169.9	214.2	271.3	328.8
Chemicals	100.0	108.0	116.6	162.0	221.2	292.8	388.0	484.2
Non-metal minerals	100.0	103.5	107.2	129.5	157.4	194.3	240.8	286.8
Other industry	100.0	103.0	106.2	126.4	152.5	187.6	232.2	277.1
Other manufacturing	100.0	103.3	106.7	127.8	154.3	189.5	233.2	276.5
Transport	100.0	104.2	108.6	134.5	167.6	210.6	265.6	320.7
Commerce	100.0	104.4	109.1	136.4	171.3	216.2	273.8	331.6
Real GDP by region								
Limpopo	100.0	104.5	109.2	136.7	171.9	217.2	275.5	334.2
Luvhuvhu-Letaba	100.0	104.4	109.1	136.0	170.4	214.4	270.9	327.5
Crocodile-Marico	100.0	104.5	109.2	136.4	171.3	216.0	273.4	331.0
Olifants	100.0	104.8	109.8	138.8	176.1	223.9	285.6	347.8
Inkomati	100.0	104.3	108.8	135.2	168.8	211.8	267.0	322.3
Usutu-Mhlatuze	100.0	104.4	108.9	135.5	169.4	212.9	268.7	324.6
Thukela	100.0	104.4	109.0	135.6	169.6	213.1	268.9	324.9
Upper Vaal	100.0	104.5	109.3	137.1	172.9	218.9	278.1	337.7
Middle Vaal	100.0	104.5	109.2	136.6	171.7	217.0	275.1	333.7
Lower Vaal	100.0	104.4	109.1	135.9	170.2	214.1	270.3	326.7
Mvoti-Umzimkulu	100.0	104.5	109.2	136.7	172.1	217.7	276.4	335.5
Mzimvubu-Keiskamma	100.0	104.4	108.9	135.5	169.2	212.1	266.9	321.5
Upper Orange	100.0	104.4	109.0	135.9	170.2	214.1	270.3	326.5
Lower Orange	100.0	104.4	109.0	135.7	169.9	214.1	270.8	328.0
Fish-Tsitsikamma	100.0	104.5	109.2	136.6	171.8	217.0	275.0	333.2
Gouritz	100.0	104.5	109.2	137.0	173.0	219.6	279.5	340.0
Indicator	2023	2024	2025	2030	2035	2040	2045	2050

Real GDP by region (continued)								
Olifants/Doorn	100.0	104.0	108.1	132.6	163.9	204.2	255.4	306.6
Breede	100.0	103.9	108.1	132.2	162.8	202.3	252.6	302.9
Berg	100.0	104.5	109.3	137.2	173.3	219.9	280.0	340.6
Employment by sector								
Agriculture	100.0	100.9	101.7	109.0	117.6	129.0	139.9	149.5
Manufacturing	100.0	101.7	103.4	110.8	117.9	124.4	131.4	136.8
Services	100.0	101.9	103.9	114.2	125.3	137.1	149.6	160.0
Household expenditure by region								
Total	100.0	104.8	109.9	139.2	177.1	225.7	288.7	352.5
Limpopo	100.0	104.4	109.1	136.1	170.5	214.1	269.9	325.8
Luvhuvhu-Letaba	100.0	104.6	109.4	137.3	173.2	218.9	277.7	336.8
Crocodile-Marico	100.0	104.9	110.0	139.8	178.5	228.0	292.3	357.4
Olifants	100.0	104.6	109.5	136.7	170.9	213.4	267.8	322.0
Inkomati	100.0	104.5	109.3	137.0	172.6	218.0	276.3	334.9
Usutu-Mhlatuze	100.0	104.6	109.5	137.8	174.5	221.3	282.0	343.3
Thukela	100.0	104.6	109.5	137.6	174.0	220.5	280.9	342.0
Upper Vaal	100.0	104.9	110.1	140.1	179.0	228.8	293.8	359.7
Middle Vaal	100.0	104.6	109.4	137.1	172.7	217.9	275.9	334.2
Lower Vaal	100.0	104.6	109.5	137.9	174.6	221.2	281.5	342.2
Mvoti-Umzimkulu	100.0	104.7	109.7	138.4	175.4	222.6	283.6	345.2
Mzimvubu-Keiskamma	100.0	104.9	110.0	140.1	179.4	230.2	296.7	364.5
Upper Orange	100.0	104.8	109.8	139.1	177.1	225.6	288.6	352.1
Lower Orange	100.0	104.3	108.8	135.1	168.6	211.3	265.4	319.6
Fish-Tsitsikamma	100.0	104.7	109.7	138.5	175.7	223.0	284.2	345.8
Gouritz	100.0	104.9	110.0	140.0	179.1	229.5	295.4	362.4
Olifants/Doorn	100.0	104.3	108.7	135.3	169.8	214.2	271.1	328.4
Breede	100.0	104.3	108.7	135.1	169.3	213.4	270.1	327.2
Berg	100.0	104.9	110.0	140.0	178.9	229.0	294.2	360.4
Relative prices								
Total	100.0	99.8	99.6	98.8	97.9	97.3	96.6	96.1
Food	100.0	99.9	99.9	99.6	99.4	99.2	99.0	98.8

Appendix D: Physical risks - RCP 8.5 (Unconstrained global emissions) select outputs, 10th percentile – percent difference relative to No Climate Change

	10th percentile							
Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Real GDP by sector								
Total	-0.6	-0.6	-0.7	-0.9	-1.2	-1.6	-2.0	-2.4
Summer cereals	*-1.8*	*-1.8*	*-1.8*	*-1.9*	*-2.6*	*-3.1*	*-3.4*	*-3.6*
Winter cereals	*-6.6*	*-6.7*	*-6.9*	*-7.8*	*-10.6*	*-12.5*	*-13.2*	*-13.2*
Citrus fruit	*-6.9*	*-6.5*	*-6.0*	*-4.5*	*-5.2*	*-5.4*	*-5.1*	*-4.7*
Deciduous fruit	*-6.7*	*-6.5*	*-6.2*	*-4.9*	*-6.5*	*-6.9*	*-6.4*	*-5.5*
Oils and fats	*-22.8*	*-22.2*	*-21.4*	*-18.8*	*-24.3*	*-25.3*	*-25.0*	*-23.5*
Cotton	*-3.9*	*-3.8*	*-3.6*	*-3.0*	*-4.6*	*-4.9*	*-5.2*	*-5.0*
Sugarcane	*-10.7*	*-10.9*	*-10.9*	*-9.3*	*-11.9*	*-11.8*	*-11.3*	*-11.6*
Vegetables	*-2.7*	*-2.7*	*-2.7*	*-2.5*	*-3.6*	*-4.2*	*-4.4*	*-4.2*
Other horticulture	*-4.2*	*-4.1*	*-4.0*	*-3.3*	*-4.3*	*-4.4*	*-4.2*	*-4.0*
Other agriculture	*-0.9*	*-0.9*	*-1.0*	*-1.2*	*-1.6*	*-2.0*	*-2.5*	*-2.8*
Mining	*-0.3*	*-0.4*	*-0.4*	*-0.7*	*-1.0*	*-1.3*	*-1.8*	*-2.3*
Food and beverages	*-1.3*	*-1.3*	*-1.3*	*-1.5*	*-2.0*	*-2.5*	*-2.9*	*-3.2*
Chemicals	*-0.4*	*-0.4*	*-0.5*	*-0.7*	*-1.0*	*-1.3*	*-1.8*	*-2.3*
Non-metal minerals	*-0.4*	*-0.5*	*-0.5*	*-0.8*	*-1.1*	*-1.4*	*-1.9*	*-2.3*
Other industry	*-0.4*	*-0.4*	*-0.5*	*-0.7*	*-1.0*	*-1.4*	*-1.9*	*-2.3*
Other manufacturing	*-0.4*	*-0.4*	*-0.5*	*-0.7*	*-1.1*	*-1.4*	*-1.9*	*-2.3*
Transport	*-0.5*	*-0.5*	*-0.5*	*-0.8*	*-1.1*	*-1.4*	*-1.9*	*-2.3*
Commerce	*-0.5*	*-0.5*	*-0.6*	*-0.8*	*-1.1*	*-1.5*	*-1.9*	*-2.3*
Real GDP by region								
Limpopo	*-0.6*	*-0.7*	*-0.7*	*-0.9*	*-1.2*	*-1.6*	*-2.0*	*-2.4*
Luvhuvhu-Letaba	*-0.5*	*-0.5*	*-0.5*	*-0.7*	*-1.1*	*-1.5*	*-1.8*	*-2.2*
Crocodile-Marico	*-0.5*	*-0.5*	*-0.6*	*-0.8*	*-1.1*	*-1.4*	*-1.9*	*-2.3*
Olifants	*-0.6*	*-0.6*	*-0.7*	*-0.8*	*-1.2*	*-1.6*	*-2.0*	*-2.4*
Inkomati	*-0.6*	*-0.6*	*-0.7*	*-0.9*	*-1.2*	*-1.5*	*-1.9*	*-2.3*
Usutu-Mhlatuze	*-1.8*	*-2.0*	*-2.0*	*-2.4*	*-2.9*	*-3.3*	*-3.7*	*-4.1*
Thukela	*-1.9*	*-1.9*	*-1.9*	*-2.2*	*-2.7*	*-3.1*	*-3.5*	*-3.9*
Upper Vaal	*-0.5*	*-0.5*	*-0.6*	*-0.8*	*-1.1*	*-1.5*	*-2.0*	*-2.4*
Middle Vaal	*-1.4*	*-1.4*	*-1.5*	*-1.7*	*-2.2*	*-2.7*	*-3.2*	*-3.5*
Lower Vaal	*-1.4*	*-1.4*	*-1.4*	*-1.6*	*-2.1*	*-2.6*	*-3.0*	*-3.4*
Mvoti-Umzimkulu	*-1.1*	*-1.1*	*-1.2*	*-1.3*	*-1.7*	*-2.0*	*-2.4*	*-2.8*
Mzimvubu-Keiskamma	*-0.5*	*-0.5*	*-0.6*	*-0.8*	*-1.1*	*-1.5*	*-1.9*	*-2.3*
Upper Orange	*-0.5*	*-0.6*	*-0.6*	*-0.8*	*-1.2*	*-1.6*	*-1.9*	*-2.3*
Lower Orange	*-0.5*	*-0.5*	*-0.5*	*-0.7*	*-1.0*	*-1.3*	*-1.6*	*-2.0*
Fish-Tsitsikamma	*-0.5*	*-0.5*	*-0.5*	*-0.8*	*-1.1*	*-1.5*	*-1.9*	*-2.3*
Gouritz	*-0.6*	*-0.6*	*-0.7*	*-0.9*	*-1.2*	*-1.5*	*-2.0*	*-2.4*
Olifants/Doorn	*-1.4*	*-1.5*	*-1.6*	*-1.6*	*-2.0*	*-2.2*	*-2.5*	*-3.0*
Breede	*-1.2*	*-1.2*	*-1.2*	*-1.2*	*-1.7*	*-2.0*	*-2.4*	*-2.6*
Berg	*-0.4*	*-0.5*	*-0.5*	*-0.8*	*-1.1*	*-1.5*	*-1.9*	*-2.4*

	10th percentile							
Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Employment by sector								
Agriculture	*-1.6*	*-1.5*	*-1.6*	*-1.8*	*-1.9*	*-2.1*	*-2.6*	*-3.1*
Manufacturing	*-0.8*	*-0.7*	*-0.7*	*-0.7*	*-0.9*	*-1.0*	*-0.9*	*-0.8*
Services	*-0.5*	*-0.5*	*-0.5*	*-0.4*	*-0.6*	*-0.6*	*-0.6*	*-0.6*
Household expenditure by region								
Total	*-1.0*	*-1.0*	*-1.0*	*-1.2*	*-1.6*	*-2.0*	*-2.5*	*-2.8*
Limpopo	*-0.9*	*-0.9*	*-0.9*	*-1.2*	*-1.7*	*-2.2*	*-2.8*	*-3.4*
Luvhuvhu-Letaba	*-1.0*	*-1.0*	*-1.1*	*-1.3*	*-1.8*	*-2.4*	*-2.9*	*-3.4*
Crocodile-Marico	*-1.2*	*-1.2*	*-1.3*	*-1.5*	*-2.1*	*-2.6*	*-3.0*	*-3.7*
Olifants	*-1.2*	*-1.2*	*-1.2*	*-1.4*	*-2.0*	*-2.4*	*-2.9*	*-3.5*
Inkomati	*-1.0*	*-1.0*	*-1.1*	*-1.4*	*-1.9*	*-2.3*	*-2.9*	*-3.6*
Usutu-Mhlatuze	*-2.0*	*-2.1*	*-2.1*	*-2.4*	*-3.0*	*-3.2*	*-3.7*	*-4.2*
Thukela	*-1.6*	*-1.6*	*-1.6*	*-2.1*	*-2.5*	*-3.0*	*-3.6*	*-4.3*
Upper Vaal	*-1.2*	*-1.2*	*-1.2*	*-1.5*	*-2.1*	*-2.6*	*-3.1*	*-3.8*
Middle Vaal	*-1.2*	*-1.2*	*-1.2*	*-1.4*	*-2.0*	*-2.5*	*-3.0*	*-3.5*
Lower Vaal	*-1.2*	*-1.2*	*-1.2*	*-1.4*	*-2.0*	*-2.5*	*-3.0*	*-3.6*
Mvoti-Umzimkulu	*-1.3*	*-1.3*	*-1.3*	*-1.5*	*-2.1*	*-2.6*	*-3.0*	*-3.6*
Mzimvubu-Keiskamma	*-1.1*	*-1.2*	*-1.2*	*-1.4*	*-2.1*	*-2.6*	*-3.1*	*-3.8*
Upper Orange	*-1.1*	*-1.1*	*-1.1*	*-1.4*	*-2.0*	*-2.5*	*-3.0*	*-3.6*
Lower Orange	*-0.9*	*-0.9*	*-0.9*	*-1.0*	*-1.5*	*-1.9*	*-2.4*	*-2.9*
Fish-Tsitsikamma	*-1.2*	*-1.2*	*-1.2*	*-1.4*	*-2.0*	*-2.5*	*-3.0*	*-3.6*
Gouritz	*-1.2*	*-1.2*	*-1.2*	*-1.4*	*-2.0*	*-2.5*	*-3.1*	*-3.7*
Olifants/Doorn	*-1.1*	*-1.2*	*-1.3*	*-1.4*	*-1.8*	*-2.2*	*-2.9*	*-3.7*
Breede	*-1.4*	*-1.4*	*-1.3*	*-1.5*	*-2.1*	*-2.5*	*-3.0*	*-3.6*
Berg	*-1.2*	*-1.2*	*-1.2*	*-1.4*	*-2.1*	*-2.6*	*-3.0*	*-3.7*
Relative prices								
All	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.2*
Food	*-0.7*	*-0.7*	*-0.7*	*-0.7*	*-0.8*	*-0.8*	*-0.9*	*-1.0*

RCP 8.5 (Unconstrained global emissions) select outputs, 50th percentile – percent difference relative to No Climate Change

	50th percentile							
Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Real GDP by sector								
Total	-0.4	-0.4	-0.4	-0.6	-0.8	-1.0	-1.3	-1.6
Summer cereals	*-1.0*	*-1.1*	*-1.0*	*-1.2*	*-1.8*	*-2.1*	*-2.4*	*-2.7*
Winter cereals	*-3.6*	*-3.7*	*-3.9*	*-4.6*	*-6.5*	*-7.3*	*-8.1*	*-8.4*
Citrus fruit	*-3.3*	*-3.3*	*-3.0*	*-2.4*	*-3.1*	*-3.1*	*-3.0*	*-3.0*
Deciduous fruit	*-1.9*	*-1.8*	*-1.7*	*-1.4*	*-2.9*	*-2.9*	*-2.6*	*-2.3*
Oils and fats	*-13.0*	*-12.5*	*-11.9*	*-10.4*	*-15.3*	*-15.9*	*-16.3*	*-15.5*
Cotton	*-2.2*	*-2.2*	*-2.1*	*-1.7*	*-3.0*	*-3.2*	*-3.4*	*-3.4*
Sugarcane	*-2.6*	*-2.6*	*-2.7*	*-0.9*	*-1.8*	*-2.5*	*-2.7*	*-3.0*
Vegetables	*-1.3*	*-1.3*	*-1.3*	*-1.3*	*-1.9*	*-2.3*	*-2.4*	*-2.4*
Other horticulture	*-1.9*	*-2.0*	*-1.9*	*-1.4*	*-2.4*	*-2.6*	*-2.6*	*-2.6*
Other agriculture	*-0.5*	*-0.5*	*-0.6*	*-0.8*	*-1.0*	*-1.3*	*-1.6*	*-1.9*
Mining	*-0.2*	*-0.2*	*-0.3*	*-0.4*	*-0.6*	*-0.8*	*-1.2*	*-1.5*
Food and beverages	*-0.7*	*-0.7*	*-0.8*	*-0.9*	*-1.3*	*-1.6*	*-1.9*	*-2.2*
Chemicals	*-0.2*	*-0.3*	*-0.3*	*-0.5*	*-0.6*	*-0.8*	*-1.2*	*-1.5*
Non-metal minerals	*-0.2*	*-0.3*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Other industry	*-0.2*	*-0.2*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Other manufacturing	*-0.2*	*-0.3*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Transport	*-0.3*	*-0.3*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Commerce	*-0.3*	*-0.3*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Real GDP by region								
Limpopo	*-0.3*	*-0.3*	*-0.4*	*-0.5*	*-0.8*	*-1.0*	*-1.3*	*-1.5*
Luvhuvhu-Letaba	*-0.2*	*-0.2*	*-0.3*	*-0.4*	*-0.7*	*-0.9*	*-1.2*	*-1.4*
Crocodile-Marico	*-0.3*	*-0.3*	*-0.4*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Olifants	*-0.3*	*-0.3*	*-0.4*	*-0.5*	*-0.8*	*-1.0*	*-1.3*	*-1.6*
Inkomati	*-0.2*	*-0.2*	*-0.2*	*-0.4*	*-0.5*	*-0.7*	*-0.9*	*-1.1*
Usutu-Mhlatuze	*-0.9*	*-1.0*	*-1.0*	*-1.2*	*-1.5*	*-1.6*	*-1.9*	*-2.1*
Thukela	*-0.9*	*-1.0*	*-0.9*	*-1.2*	*-1.7*	*-2.0*	*-2.4*	*-2.6*
Upper Vaal	*-0.3*	*-0.3*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.3*	*-1.6*
Middle Vaal	*-0.7*	*-0.7*	*-0.8*	*-0.9*	*-1.3*	*-1.6*	*-2.0*	*-2.2*
Lower Vaal	*-0.7*	*-0.8*	*-0.8*	*-0.9*	*-1.3*	*-1.7*	*-2.0*	*-2.2*
Mvoti-Umzimkulu	*-0.4*	*-0.4*	*-0.4*	*-0.4*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Mzimvubu-Keiskamma	*-0.3*	*-0.3*	*-0.4*	*-0.5*	*-0.7*	*-1.0*	*-1.2*	*-1.5*
Upper Orange	*-0.3*	*-0.3*	*-0.4*	*-0.5*	*-0.7*	*-1.0*	*-1.2*	*-1.5*
Lower Orange	*-0.2*	*-0.2*	*-0.2*	*-0.3*	*-0.6*	*-0.8*	*-1.0*	*-1.2*
Fish-Tsitsikamma	*-0.3*	*-0.3*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*
Gouritz	*-0.3*	*-0.4*	*-0.4*	*-0.5*	*-0.7*	*-1.0*	*-1.3*	*-1.6*
Olifants/Doorn	*-0.9*	*-1.0*	*-1.0*	*-1.0*	*-1.2*	*-1.3*	*-1.6*	*-1.9*
Breede	*-0.3*	*-0.3*	*-0.3*	*-0.6*	*-0.9*	*-1.2*	*-1.4*	*-1.6*
Berg	*-0.3*	*-0.3*	*-0.3*	*-0.5*	*-0.7*	*-0.9*	*-1.2*	*-1.5*

	50th percentile							
Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Employment by sector								
Agriculture	*3.5*	*3.5*	*3.2*	*3.1*	*4.6*	*4.7*	*4.6*	*4.0*
Manufacturing	*-0.3*	*-0.3*	*-0.3*	*-0.3*	*-0.4*	*-0.4*	*-0.4*	*-0.3*
Services	*-0.2*	*-0.2*	*-0.2*	*-0.2*	*-0.3*	*-0.3*	*-0.3*	*-0.3*
Household expenditure by region								
Total	*-0.5*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.3*	*-1.6*	*-1.9*
Limpopo	*-0.6*	*-0.7*	*-0.7*	*-0.8*	*-1.2*	*-1.5*	*-1.8*	*-2.1*
Luvhuvhu-Letaba	*-0.7*	*-0.7*	*-0.7*	*-0.9*	*-1.2*	*-1.6*	*-1.9*	*-2.2*
Crocodile-Marico	*-0.8*	*-0.9*	*-0.9*	*-1.0*	*-1.4*	*-1.8*	*-2.1*	*-2.4*
Olifants	*-0.8*	*-0.8*	*-0.9*	*-0.9*	*-1.4*	*-1.7*	*-2.0*	*-2.3*
Inkomati	*-0.4*	*-0.5*	*-0.5*	*-0.7*	*-0.8*	*-1.1*	*-1.5*	*-1.8*
Usutu-Mhlatuze	*-0.9*	*-1.0*	*-1.0*	*-1.3*	*-1.6*	*-1.9*	*-2.3*	*-2.5*
Thukela	*-1.0*	*-1.0*	*-1.0*	*-1.3*	*-1.8*	*-2.2*	*-2.5*	*-2.8*
Upper Vaal	*-0.9*	*-0.9*	*-0.9*	*-1.0*	*-1.4*	*-1.8*	*-2.1*	*-2.4*
Middle Vaal	*-0.8*	*-0.8*	*-0.8*	*-0.9*	*-1.4*	*-1.7*	*-2.0*	*-2.3*
Lower Vaal	*-0.9*	*-0.9*	*-0.9*	*-1.0*	*-1.4*	*-1.7*	*-2.0*	*-2.3*
Mvoti-Umzimkulu	*-0.8*	*-0.9*	*-0.9*	*-1.0*	*-1.5*	*-1.8*	*-2.1*	*-2.4*
Mzimvubu-Keiskamma	*-0.8*	*-0.8*	*-0.9*	*-1.0*	*-1.4*	*-1.8*	*-2.2*	*-2.5*
Upper Orange	*-0.8*	*-0.8*	*-0.8*	*-0.9*	*-1.4*	*-1.7*	*-2.0*	*-2.3*
Lower Orange	*-0.5*	*-0.5*	*-0.5*	*-0.7*	*-1.0*	*-1.3*	*-1.6*	*-1.9*
Fish-Tsitsikamma	*-0.8*	*-0.8*	*-0.9*	*-1.0*	*-1.4*	*-1.7*	*-2.0*	*-2.4*
Gouritz	*-0.8*	*-0.9*	*-0.9*	*-1.0*	*-1.4*	*-1.7*	*-2.1*	*-2.4*
Olifants/Doorn	*-0.7*	*-0.8*	*-0.8*	*-0.8*	*-1.1*	*-1.3*	*-1.7*	*-2.2*
Breede	*-0.8*	*-0.8*	*-0.8*	*-0.9*	*-1.4*	*-1.7*	*-2.1*	*-2.4*
Berg	*-0.8*	*-0.8*	*-0.9*	*-1.0*	*-1.4*	*-1.7*	*-2.1*	*-2.4*
Relative prices								
All	*0.2*	*0.2*	*0.2*	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*
Food	*0.5*	*0.5*	*0.5*	*0.4*	*0.5*	*0.6*	*0.6*	*0.6*

RCP 8.5 (Unconstrained global emissions) select outputs, 90th percentile – percent difference relative to No Climate Change

	90th percentile							
Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Real GDP by sector								
Total	0.1	0.1	0.1	0.1	0.0	-0.1	-0.2	-0.4
Summer cereals	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*
Winter cereals	*1.2*	*1.2*	*1.3*	*1.4*	*1.9*	*1.9*	*2.7*	*3.2*
Citrus fruit	*4.0*	*3.7*	*3.5*	*2.7*	*2.3*	*1.8*	*1.5*	*1.4*
Deciduous fruit	*4.6*	*4.3*	*4.3*	*4.2*	*4.5*	*3.9*	*3.8*	*3.8*
Oils and fats	*7.4*	*6.8*	*6.4*	*6.1*	*8.3*	*7.8*	*8.4*	*9.7*
Cotton	*1.7*	*1.6*	*1.5*	*1.4*	*1.7*	*1.4*	*1.3*	*1.4*
Sugarcane	*8.7*	*9.0*	*9.3*	*8.8*	*9.6*	*9.3*	*9.5*	*10.5*
Vegetables	*0.9*	*0.9*	*0.9*	*0.9*	*1.0*	*1.0*	*1.1*	*1.0*
Other horticulture	*2.7*	*2.6*	*2.6*	*2.4*	*2.4*	*2.0*	*2.0*	*2.0*
Other agriculture	*0.2*	*0.1*	*0.1*	*0.1*	*0.0*	*0.0*	*-0.1*	*-0.3*
Mining	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.2*	*-0.4*	*-0.6*
Food and beverages	*0.3*	*0.3*	*0.3*	*0.2*	*0.2*	*0.1*	*0.0*	*-0.1*
Chemicals	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.2*	*-0.4*	*-0.6*
Non-metal minerals	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.1*	*-0.2*	*-0.4*	*-0.5*
Other industry	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.1*	*-0.2*	*-0.4*	*-0.5*
Other manufacturing	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.1*	*-0.2*	*-0.4*	*-0.5*
Transport	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.3*	*-0.5*
Commerce	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.3*	*-0.5*
Real GDP by region								
Limpopo	*0.1*	*0.1*	*0.1*	*0.0*	*-0.1*	*-0.2*	*-0.4*	*-0.5*
Luvhuvhu-Letaba	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.2*	*-0.4*	*-0.6*
Crocodile-Marico	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.3*	*-0.5*
Olifants	*0.1*	*0.1*	*0.1*	*0.0*	*-0.1*	*-0.1*	*-0.3*	*-0.5*
Inkomati	*0.3*	*0.3*	*0.4*	*0.4*	*0.6*	*0.7*	*0.8*	*0.8*
Usutu-Mhlatuze	*0.2*	*0.1*	*0.2*	*0.0*	*0.1*	*0.2*	*0.3*	*0.2*
Thukela	*1.1*	*1.0*	*1.1*	*1.0*	*1.1*	*1.0*	*0.8*	*0.7*
Upper Vaal	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.3*	*-0.5*
Middle Vaal	*0.4*	*0.4*	*0.4*	*0.3*	*0.4*	*0.4*	*0.3*	*0.1*
Lower Vaal	*0.4*	*0.4*	*0.4*	*0.4*	*0.3*	*0.3*	*0.2*	*0.1*
Mvoti-Umzimkulu	*0.5*	*0.6*	*0.6*	*0.5*	*0.5*	*0.4*	*0.3*	*0.2*
Mzimvubu-Keiskamma	*0.0*	*0.1*	*0.0*	*0.0*	*-0.1*	*-0.1*	*-0.3*	*-0.4*
Upper Orange	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.1*	*-0.3*	*-0.4*
Lower Orange	*0.1*	*0.1*	*0.1*	*0.0*	*-0.1*	*-0.2*	*-0.3*	*-0.6*
Fish-Tsitsikamma	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.3*	*-0.5*
Gouritz	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.4*	*-0.5*
Olifants/Doorn	*-0.5*	*-0.5*	*-0.6*	*-0.6*	*-0.7*	*-0.8*	*-0.9*	*-1.2*
Breede	*0.9*	*0.8*	*0.8*	*0.6*	*0.4*	*0.2*	*-0.1*	*-0.3*
Berg	*0.0*	*0.0*	*0.0*	*0.0*	*-0.1*	*-0.2*	*-0.3*	*-0.5*

	90th percentile							
Indicator	2023	2024	2025	2030	2035	2040	2045	2050
Employment by sector								
Agriculture	*7.4*	*7.3*	*7.1*	*6.6*	*8.8*	*9.6*	*9.4*	*8.4*
Manufacturing	*0.2*	*0.1*	*0.1*	*0.2*	*0.2*	*0.3*	*0.4*	*0.4*
Services	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.2*
Household expenditure by region								
Total	*0.2*	*0.2*	*0.2*	*0.1*	*0.1*	*0.0*	*-0.1*	*-0.3*
Limpopo	*-0.4*	*-0.5*	*-0.5*	*-0.6*	*-0.9*	*-1.2*	*-1.5*	*-1.7*
Luvhuvhu-Letaba	*-0.5*	*-0.5*	*-0.5*	*-0.6*	*-1.0*	*-1.2*	*-1.5*	*-1.8*
Crocodile-Marico	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.4*	*-1.6*	*-1.9*
Olifants	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.3*	*-1.6*	*-1.8*
Inkomati	*-0.2*	*-0.2*	*-0.2*	*-0.4*	*-0.5*	*-0.6*	*-0.9*	*-1.1*
Usutu-Mhlatuze	*-0.6*	*-0.6*	*-0.6*	*-0.9*	*-0.9*	*-1.2*	*-1.6*	*-1.7*
Thukela	*-0.6*	*-0.6*	*-0.5*	*-0.9*	*-1.2*	*-1.5*	*-1.8*	*-2.0*
Upper Vaal	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.4*	*-1.7*	*-1.9*
Middle Vaal	*-0.5*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.3*	*-1.6*	*-1.9*
Lower Vaal	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.4*	*-1.6*	*-1.9*
Mvoti-Umzimkulu	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.4*	*-1.7*	*-1.9*
Mzimvubu-Keiskamma	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.4*	*-1.7*	*-2.0*
Upper Orange	*-0.5*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.3*	*-1.6*	*-1.9*
Lower Orange	*-0.3*	*-0.3*	*-0.3*	*-0.4*	*-0.8*	*-1.0*	*-1.2*	*-1.5*
Fish-Tsitsikamma	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.3*	*-1.6*	*-1.9*
Gouritz	*-0.6*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.3*	*-1.7*	*-1.9*
Olifants/Doorn	*-0.6*	*-0.7*	*-0.7*	*-0.7*	*-0.8*	*-1.0*	*-1.4*	*-1.8*
Breede	*-0.4*	*-0.4*	*-0.4*	*-0.6*	*-1.0*	*-1.2*	*-1.5*	*-1.8*
Berg	*-0.5*	*-0.6*	*-0.6*	*-0.7*	*-1.1*	*-1.3*	*-1.6*	*-1.9*
Relative prices								
All	*0.4*	*0.4*	*0.4*	*0.3*	*0.4*	*0.4*	*0.4*	*0.4*
Food	*1.4*	*1.4*	*1.4*	*1.3*	*1.7*	*1.7*	*1.6*	*1.6*