



GREENBOOK
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THE ECONOMIC EFFECTS OF CLIMATE CHANGE ON SETTLEMENTS

WORKSTREAM 4: RESEARCH REPORT

2019



www.greenbook.co.za

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Funded by



International Development Research Centre
Centre de recherches pour le développement international





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Date	2019
ToDB reference	CSIR/BE/SPS/ER/2019/0007/C
Suggested citation	Ngepah, N & Djemo, C. R. 2019. <i>Green Book – The economic effects of climate change on settlements</i> . Technical report, Pretoria: CSIR & AIIG

Disclaimer and acknowledgement: *This work was carried out with the aid of a grant from the CSIR Long-term Thematic Programme, Pretoria, South Africa and the International Development Research Centre, Ottawa, Canada. The views expressed herein do not necessarily represent those of the IDRC or its Board of Governors.*



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1 INTRODUCTION

South Africa's socioeconomic landscape is still marred with the triple challenge of unemployment, poverty and inequality. The National Development Plan (NDP) ambitiously set a target of reducing unemployment from 24.9% in 2012 to less than 6% in 2030. For this to happen, the economy's Gross Domestic Product (GDP) has to grow by more than 2% in real terms and about 7% if inflation is taken into account. Since the launch of the NDP, South Africa's economy has grown rather sluggishly compared to the rest of Africa. As the developed world and other emerging markets are facing a somewhat positive economic outlook, South Africa's outlook has remained bleak due to internal governance issues. Although investor confidence seems to be slowly returning following the early 2018 change in government, climate change is likely to constitute a significant burden on South Africa's projected economic performance.

This chapter assesses the effect of climate change, captured by long-term changes in average temperatures, on the economic output of South Africa. The estimated effects are then used together with projected future temperature scenarios for South Africa to forecast possible economic losses due to climate change. We have adapted provincial level estimates to the municipal economic structures to forecast losses at a municipality level for the forecast horizons of 2030 and 2050. In section two we present the background to South Africa's socio-economic and climate conditions that necessitated this analysis. Section three briefly describes the methodology used. The output is presented and discussed in section four. We conclude in section five and draw policy lessons in section six.

2 BACKGROUND

South Africa has already experienced the adverse impacts of climate-induced hazards. Although the country has relatively low carbon dioxide (CO₂) emissions (0.97% of world total emissions), climate change in South Africa has led to various costly floods and droughts. South Africa is located at 22° – 34° latitude and 16° – 32° longitude. Administratively, it is divided into nine provinces: The Eastern Cape, the Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, the Northern Cape, the North West, and the Western Cape. According to Benhin (2006), the country is divided into four main climatic zones. The first zone is the desert, covering a large part of the Northern Cape and the northeastern part of the Western



Cape. The arid zone spans Limpopo, Mpumalanga, North West, Free State, western KwaZulu-Natal, Eastern Cape and the northern areas of the Western Cape. The sub-tropical wet zone covers the coastal areas of KwaZulu-Natal and the Eastern Cape. Finally, the mediterranean or winter rainfall area spreads over the southwestern coast of the Western Cape.

South African climate is generally dry with sunny days and cool nights. Temperatures are more influenced by variations in elevation, terrain and ocean currents than latitudes (Benhin, 2006). Bloemfontein appears as the coldest city with winter temperatures below -3°C . According to Palmer and Ainslie (2002), the average temperature in Cape Town was 17°C in 2002. This average has increased to 19.4°C in 2014 (World Bank, 2015).

Winter temperatures on average vary across the country between 5°C and 12°C with low levels occurring in the Eastern Cape. The highest maximum summer temperature is recorded in the Northern Cape and Mpumalanga (49°C) whereas the coolest temperature occurs in winter with temperatures between 0° and -2°C (US Library of Congress, 2009). Most of the country has warm, sunny days and cool nights with rainfall occurring most often during the summer season (November to March). However, in the southwestern parts of the Western Cape, rainfall occurs in winter (June to August) and temperatures in that location are influenced by variation in elevation of sea level.

At the request of the Intergovernmental Panel on Climate Change (IPCC), the climate science community has developed a set of new guidelines for climate scenario projections known as the Representative Concentration Pathways (RCP). Van Vuuren et al. (2011) reviews the main RCPs commonly used in climate science. There are four RCPs each defining a specific emission trajectory and ultimate radiative forcing. The pathways respectively lead to radiative forcing levels of 8.5, 6, 4.5 and 2.6 Wm^{-2} by 2100. The baseline trajectory is the RCP8.5 which assumes high population, low economic growth and high energy intensity with little technological advancement. The RCP2.6 is an ambitious policy scenario leading to low levels of forcing. At the current levels of emission cutting commitments, this scenario is implausible. The two intermediary trajectories are the RCP6 and RCP4.5. The RCP4.5 is considered the modal scenario with most mitigation policy projections leading to it. This project considers the baseline (RCP8.5) and the modal mitigation (RCP4.5) scenarios.

South Africa's average temperatures are expected to rise significantly over the rest of this century. The RCP8.5 series shows an above 5°C increase by the end of the century relative to the 1990-2000 average temperatures. The mitigation scenario that yields the RCP4.5 would



result in a maximum of 2°C increase in average temperatures by 2100. Over the 2050 forecast horizon considered in this work, the RCP8.5 will result in a 2.54°C increase compared with 1.64°C increase in the RCP4.5 scenario.

These projected changes are likely to affect South Africa's economic output to the extent that the output responds to changes in temperatures. One feature of the assessment of the climate change impact on the economy is the complexity of the climate-economy relationship. Various sector-specific studies around the world and in South Africa suggest significant effects of climate change on agriculture (Guiteras, 2009), ocean fisheries, access to fresh water, migration, tourism and other factors (IPCC, 2007). However, there is less evidence of a direct link between climate change and economic growth, especially related to productivity. Temperature changes can affect human capital through health (Deschenes and Moretti, 2007), crime (Jacob et al., 2007) and conflicts (Miguel et al., 2004). Extreme events can also erode physical infrastructure. All of these factors can affect economic activities directly or indirectly. Most of South Africa's productive sectors have significant exposure to climate change risks.

South Africa is an emerging economy with a high dependence on extractive resources such as coal, copper, gold, and platinum. The services sector is well-developed. Financial services dominate this sector, with a stock exchange ranking among the top 20 in the world and the largest in Africa. The 2016 population of South Africa is estimated at 56 million, with a GDP per capita of \$13.4 in 2017. Unemployment and inequality in South Africa are among the highest in the world with a Gini coefficient of between 0.66 and 0.70. The unemployment rate is around 27% of the workforce; the percentage of black youth is even higher. The poverty headcount in 2017, estimated by Statistics South Africa (Statssa, 2017) using 2015 data, is above 50%.

Four main sectors contribute to South African value addition (see Table 1). The largest sector is that of services, followed by the manufacturing, mining and agricultural sectors. All these sectors are likely to be affected in one way or the other by climate change - through direct impact in certain sectors like agriculture, fishery, forestry and water, but also indirectly through the impact on physical and human capital inputs to production.



Table 1: Trend of South Africa's economic structure by value addition*

	1993-1999	2004-2000	2005-2009	2010-2014
Agriculture	2.48%	2.36%	2.12%	2.19%
Forestry	0.46%	0.44%	0.42%	0.43%
Fishery	0.15%	0.12%	0.11%	0.13%
Mining	14.96%	12.96%	10.58%	8.74%
Manufacturing	15.90%	16.21%	15.88%	15.09%
Electricity and gas	2.60%	2.41%	2.37%	2.08%
Water	0.81%	0.68%	0.60%	0.64%
Services	62.65%	64.82%	67.91%	70.70%
Total value added (R Billions)	10 695.09	9 256.215	11 337.85	12 588.02

* Computed by authors using data from Quantec

2.1 Economics of climate change in literature

Based on existing literature on the impact of climate change on economic growth viewed from the perspective of a country level, this study attempts to investigate the impact of climate change on economic growth in South Africa at the municipal and provincial levels. In contrast to the approach adopted by this study, Akram and Hamid (2015) investigated the impact of climate change on Pakistan's economic growth at a country level with temperature as a proxy for climate change. Their study found that climate change had a negative and significant relationship with GDP and with productivity in the manufacturing and services sectors. Climate change had a very strong, even devastating, effect in the agricultural sector. A similar study at country level done in Brazil by Tebaldi and Beaudin (2016) shows that climate events could enhance inequality and have significant adverse rainfall variations that can affect GDP growth rates in the poorest regions. In addition to this, Brown et al. (2010) argued that precipitation is the most significant climate event that impacts GDP growth in Sub-Saharan African countries whereas temperature variability shows a significant effect in some regions. Henceforth, using precipitation as a proxy of climate change events is likely to produce more significant results in Sub-Sahara African country rather than using temperature as a proxy. It is however very important to include both climate variables for robustness analysis. Abidaye and Odusola (2015) presented evidence that an increase of 1°C in temperature reduces GDP growth by 0.67%. This will have a significant negative impact on economic growth in Africa. Furthermore, they argue that long term temperature variability affects long term economic growth in Africa. Contrary to Brown et al. (2010) who argue that temperature variability has a significant impact only in some African regions, Dell et al, (2012) pointed out that higher temperatures reduce



economic growth in the poorest countries substantially with only little effect in the richest countries. Furthermore, Dell et al, (2012) find evidence that higher temperatures have severe effects in poor countries by reducing agricultural output, industrial output, aggregate investment and by increasing political instability. As South Africa is known as a country with high inequality indicators among some rural municipalities, this previous finding will be a key guideline in further studies. Golub and Toman (2015) examined the impact of climate change on productivity in the global economy. Results show that industrial transformation barriers (posed by set-up costs) can lead to an optimal path without the uptake of less climate-sensitive technology, without decarbonization and with stagnant growth. They emphasized that lower set-up costs can lead to an efficient growth path that incorporates the introduction of less vulnerable and low carbon technology. These results are based on the theory that the greater the carbon intensity of existing production, the more damaging accumulated emissions are for economic growth, and the lower the rate of utility discounting (which increases the present value cost of long-term losses due to climate change).

3 METHODOLOGY

There are various modelling approaches to simulate the effects of climate change. The approaches can also be applied at various levels: micro-local area, within-country sub-regional level, national and cross-country levels. A choice regarding the various economic sectors to focus on also needs to be made. Several studies have paid attention to the agricultural sector because of its direct exposure to climatic factors. Because of inter-sector linkages of the economy, climate change can have both direct and indirect effects on the economy. Each approach has its strengths and weaknesses. For example, examining the effects that encompass direct and indirect effects may require the use of the computable general equilibrium (CGE) methodology. However, this usually relies on social accounting matrix data that are usually obsolete. The CGE method is also very data-intensive and may lead to implausible assumptions in the absence of the required data.

In this project, we are interested in assessing effects at municipal, provincial and national levels for different economic sectors in South Africa. We opted for an econometric and forecasting methodology that can optimise the available data, while also catering for certain biases that may arise due to data issues. These are discussed below.



3.1 Econometric modelling

The model we used to develop our econometric framework is based on the well-known theoretical foundation of neoclassical economic growth models (Solow, 1956) underpinned by economic production functions. The motivation behind the use of this model comes from the fact that it does not require complete knowledge of the distribution of data and also provides a straightforward way to test a specification of the proposed model.

The starting point of the model is the usual Cobb-Douglas production function adapted for climate factors. The model factors climate variables as arguments of total factor productivity. In the function, climate parameters enter exogenously, affecting both the productivity of capital and labour in economic output determination. Temperature and rainfall are controlled as climate factors. Taking time derivatives of per-worker specifications of the function, we derived an equation for productivity growth which is a function of capital per worker and climatic factors. We also considered the equation for the steady state of the economy, which is a function of initial conditions of the economy and climatic factors. A particular adjustment in this case is that we modelled for the municipality-level neighbourhood effects – the effect that adjacent municipalities have on your municipality - which have often been neglected in previous analyses. It is plausible that a given municipality's output and/or climate factors can be significantly affected by the climate of its surrounding municipalities. We found that it was important to control for this cross-municipality dependence to estimate the true effects of climate change more precisely.

Equation (1) is an expression of change in technology, or total factor productivity. Replacing the term in (2) with its expression in (1), and rearranging gives:

$$g_{it} = g_i + (\beta_1 + \delta_1)T_{it} + (\beta_2 + \delta_2)R_{it} + (\beta_3 + \delta_3)SPT_{it} + (\beta_4 + \delta_4)SPR_{it} - (\beta_1 T_{it-1} + \beta_2 R_{it-1} + \beta_3 SPT_{it-1} + \beta_4 SPR_{it-1}) + \alpha \Delta \ln k_{it} + \varepsilon_{it} \quad (1)$$

Or

$$g_{it} = g_i + (\beta_1 + \delta_1)T_{it} + (\beta_2 + \delta_2)R_{it} + (\beta_3 + \delta_3)SPT_{it} + (\beta_4 + \delta_4)SPR_{it} - (\beta_1 T_{it-1} + \beta_2 R_{it-1} + \beta_3 SPT_{it-1} + \beta_4 SPR_{it-1}) + \alpha \Delta \ln k_{it} + \varepsilon_{it} \quad (2)$$



Where lower case letters and natural logs of the corresponding variables and $\gamma = \beta + \delta$ is a combination of the short-run and long-run effects.

3.2 Variables and Data

The successful estimation of the true coefficient of the impact of climate change on growth requires six sets of variables adapted to fit the underlying econometric model. These are GDP or GDP growth rates; capital per worker; annual average temperatures; annual average rainfall; spatial dependence indicators for temperature; and rainfall.

The main climate-related variables (temperature and rainfall) were obtained as a set of detailed projections of future climate change generated for South Africa. The set was developed using a variable resolution global climate model (GCM) developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). 8 km resolution projections were obtained by further downscaling of the CSIR's existing set of 50 km resolution CORDEX (Coordinated Regional Downscaling Experiment) projections of future climate change.

The simulations cover the period from 1960 to 2100, with RCP4.5 and RCP8.5 capturing high and low mitigation scenarios respectively. The simulations were undertaken by a team of experts of the Centre for High Performance Computing (CHPC) at the Meraka Institute of the Council for Scientific and Industrial Research (CSIR) in South Africa. The specific GCM's ability to simulate present day Southern Africa climate has been well demonstrated in existing literature (Van Vuuren et al., 2011). The simulations were necessary for the predictions of future climates up to our forecast horizon. However, the data used for the estimation of the econometric model is based on historical figures of actually observed climate data supplied by the CSIR.

The economic growth indicator was computed using value-added measures for different economic sectors at the municipality level in South Africa. Capital per worker was the ratio of gross fixed capital formation to employment and was also for different economic sectors at municipality level. Value-added figures, together with capital and labour were sourced from QUANTEC.



There is a great deal of econometric bias that can arise when one ignores the effect of cross municipality dependence. In order to effectively isolate the effect of climate change, it is necessary to control and isolate the impact of neighbouring municipalities. We generated spatial effects variables for temperature and rainfall by computing a weighted matrix of temperature and rainfall, where the weights are proportional to the geographic distance between two municipalities. The econometric model allows for the isolation of short-run and long-run effects. For this reason, we introduced the one period lag for each of our explanatory variables to produce the autoregressive model in Equation (2).

The econometric model was estimated using a technique known as the System's Generalised Method of Moments. This technique is the most appropriate for the type of data we are using because of two reasons. Firstly, it is able to correct for the bias introduced by the problem of double causation known in econometrics as endogeneity. This is often the result of either a regression equation specified with some relevant variables omitted or the fact that the variables in the model might be mutually caused one another. Secondly, this technique is able to exploit municipality-specific information to improve the estimated coefficient of the effect of climate change.

From the estimated coefficients, the long-run (L-R) and short-run (S-R) effects can be computed and the values are reported in Table 2. We made use of long-run coefficients for forecasting because of the long-time horizon (2030 and 2050) in our forecasting model. For the purpose of forecasting, the model is estimated at the provincial level, where sub-samples have been drawn for the municipalities of a specific province. The provincial level coefficients for each of the economic sectors are allocated to each municipality within a given province.



Table 2: Long-run and short-run coefficients based on the regression output

		EC	FS	GT	KZN	Lim.	MP	NW	NC	WC
<i>Manu.</i>	L-R coef	-	-	-	-	0.006	-	-	-	0.009
		0.021	0.009	0.004	0.031		0.004	0.004	0.014	
<i>Mining</i>	S-R coef	0.000	-	-	-	0.017	0.015	-	0.000	0.054
			0.019	0.015	0.011			0.017		
<i>Serv.</i>	L-R coef	-	-	-	-	-	-	-	-	0.052
		0.073	0.081	0.065	0.089	0.099	0.076	0.090	0.025	
<i>Agric.</i>	S-R coef	-	-	-	-	-	-	-	-	0.068
		0.032	0.083	0.068	0.047	0.081	0.081	0.082	0.025	
<i>Forest.</i>	L-R coef	-	0.003	-	-	-	0.003	0.008	0.000	-
		0.008		0.006	0.012	0.004				0.014
<i>Fisheries</i>	S-R coef	0.007	0.011	0.008	-	0.015	0.018	0.010	0.019	-
					0.001					0.003
<i>Elec. & Gas</i>	L-R coef	0.026	-	0.021	0.055	-	0.094	0.068	0.046	-
			0.007			0.030				0.055
<i>Water</i>	S-R coef	0.013	0.035	0.070	0.098	0.080	0.184	0.101	0.083	-
										0.069
<i>Water</i>	L-R coef	0.025	0.025	0.037	0.040	0.081	0.033	0.042	0.048	-
										0.042
<i>Water</i>	S-R coef	0.046	0.079	0.093	0.074	0.170	0.091	0.064	0.060	-
										0.029
<i>Water</i>	L-R coef	0.021	0.025	0.012	0.059	0.062	0.036	0.042	0.057	-
										0.054
<i>Water</i>	S-R coef	0.042	0.076	0.074	0.097	0.180	0.089	0.083	0.066	-
										0.057
<i>Water</i>	L-R coef	-	-	0.006	-	0.003	0.022	-	0.026	-
		0.035	0.005		0.035			0.008		0.025
<i>Water</i>	S-R coef	0.035	0.075	0.067	0.053	0.114	0.121	0.057	0.075	0.010
<i>Water</i>	L-R coef	0.024	0.021	0.017	0.016	0.045	0.009	0.039	0.058	0.076
<i>Water</i>	S-R coef	0.017	-	0.007	-	0.011	0.006	0.029	0.069	0.115
			0.003		0.027					

The forecasting technique uses the temperature changes in 2030 and 2050 relative to the 1995-2000 average levels to generate new values of the economy for those periods. The forecast is based on the underlying production function from which Equation (2) is derived. The equation links levels of output or real value added to climate variables and other inputs. To calculate the future impact of climate change, we keep the effects of other variables constant. As such, the projected impact of climate change is simply the long-run coefficients (in Table 2) multiplied by the average real value added for the reference base period of 1990-2000 and the change in temperature from the reference period to the projection horizon of 2050. It is important to note that the projection horizon is taken as a 10-year average from 2041 to 2050. Hence, the temperature change is the difference between the 2041-2050 mean and the 1995-2000 mean.



Figure 1 shows the evolution of mean deviations from mean temperatures of the period 1990-2000 based on the baseline RCP8.5 and the plausible mitigation scenario RCP4.5. It is evident from the graph that the temperature cost of inaction is significant. However, the gap between the two scenarios in the 2050 horizon is less pronounced than in the later part of the century. In this respect, our projections of the economic costs of climate change are conservative given the significant gap between RCP4.5 and RCP8.5 beyond 2050. The projected economic losses are significant nonetheless.

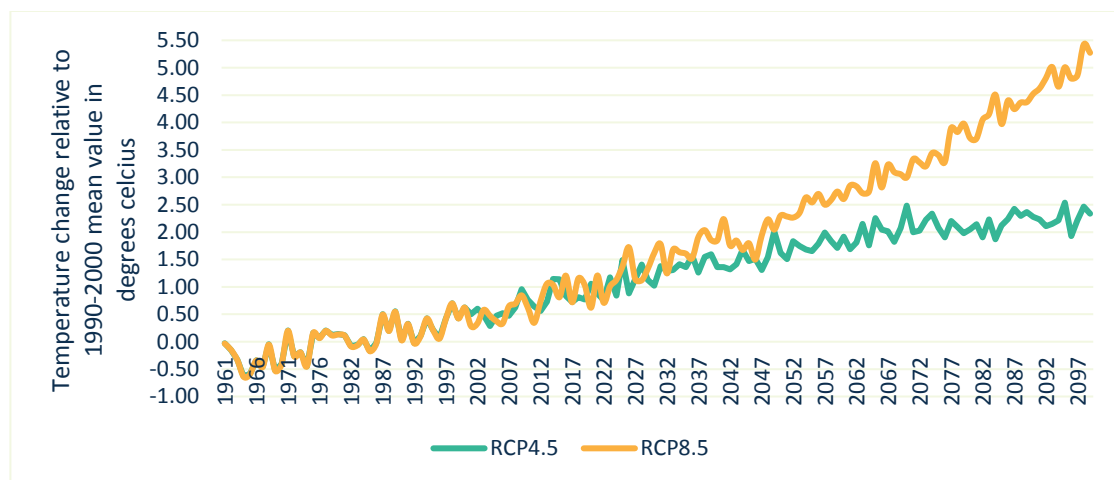


Figure 1: Climate scenario projections

3.3 Robustness check

Before examining the results of the forecast of climate effects, we first undertook a robustness check of the performance of the estimated model in forecasting. To do this, we used the estimated coefficients to do an out-of-sample forecast for the span of the data. The forecast series are compared with the actual in a t-test and fitted scatter plots. The scatter plot points are all within the 95% confidence interval. The results of the t-test are reported in Table 3.

Table 3: T-test on mean difference between the forecast and actual values

		Mean	SE	t-stat (P-value)	Decision
<i>Overall</i>	Actual	0.025	0.001	1.614 (0.107)	No statistical diff. in mean
	Forecast	0.024	0.001		
<i>Eastern Cape</i>	Actual	0.021	0.001	0.227 (0.821)	No statistical diff. in mean
	Forecast	0.021	0.001		



<i>Free State</i>	Actual	0.033	0.003	0.801 (0.423)	No statistical diff. in mean
	Forecast	0.031	0.003		
<i>Gauteng</i>	Actual	0.015	0.003	-0.003 (0.998)	No statistical diff. in mean
	Forecast	0.015	0.201		
<i>KwaZulu- Natal</i>	Actual	0.027	0.001	1.221 (0.223)	No statistical diff. in mean
	Forecast	0.025	0.002		
<i>Limpopo</i>	Actual	0.025	0.002	-0.634 (0.526)	No statistical diff. in mean
	Forecast	0.027	0.002		
<i>Mpumalanga</i>	Actual	0.022	0.002	0.663 (0.507)	No statistical diff. in mean
	Forecast	0.021	0.002		
<i>North West</i>	<i>Actual</i>	<i>0.023</i>	<i>0.002</i>	<i>1.890</i> <i>(0.060)</i>	<i>Significant men</i> <i>diff. at 10%</i>
	<i>Forecast</i>	<i>0.018</i>	<i>0.003</i>		
<i>Northern Cape</i>	Actual	0.023	0.002	0.900 (0.369)	No statistical diff. in mean
	Forecast	0.021	0.003		
<i>Western Cape</i>	Actual	0.033	0.002	1.092 (0.275)	No statistical diff. in mean
	Forecast	0.032	0.003		

At the national level, the forecast approximates the actual series more precisely. The municipal-level analyses are done using coefficients generated at the provincial level. Hence, in addition to the overall forecast, we also undertook forecasts for each provincial panel. Eight of the nine provinces perform very well with their respective forecasts closely mimicking the actual panels. The hypothesis of zero mean difference between the forecast and the actual was rejected at 10% significance level in the North West province. However, we still used the estimated coefficients to perform out-of-sample forecasts for municipalities in the North West province. This is because the mean difference is only 0.005 and the relatively weak power of forecast arises from the fact that there are fewer observations for that province. The mean difference for this province is however only significant at the 10% level. It is possible, however, that the results of the forecasts are weaker for the municipalities and towns in the North West province. With this confidence in the performance of the model, we proceed with the discussion of the forecast effects below.



4 RESULTS

The results show that climate change will exert a significant drag on economic expansion in South Africa by 2030 and 2050. There is a very high economic cost to doing nothing about climate change (RCP8.5). However, even the best plausible mitigation scenario (RCP4.5) still shows significant economic losses by 2030 and 2050. In what follows, we first present the national picture by various sectors, comparing both the plausible mitigation scenario (RCP4.5) with the business-as-usual (BAU) scenario (RCP8.5). The provincial results are then discussed. We end the discussion of the economic effects of climate change with the local (municipality-level) findings.

4.1 National picture

Our projections show that South Africa's economy will lose significant output in GDP relative to the 1995-2000 levels. South Africa's economy would lose about R28.4 billion on average due to climate change following the RCP4.5 scenario and R35.7 billion following the RCP8.5 scenario by 2030. By 2050, the losses will be R29.3 billion and R38.1 billion respectively. The year-by-year national percentage losses are plotted in Figure 2.

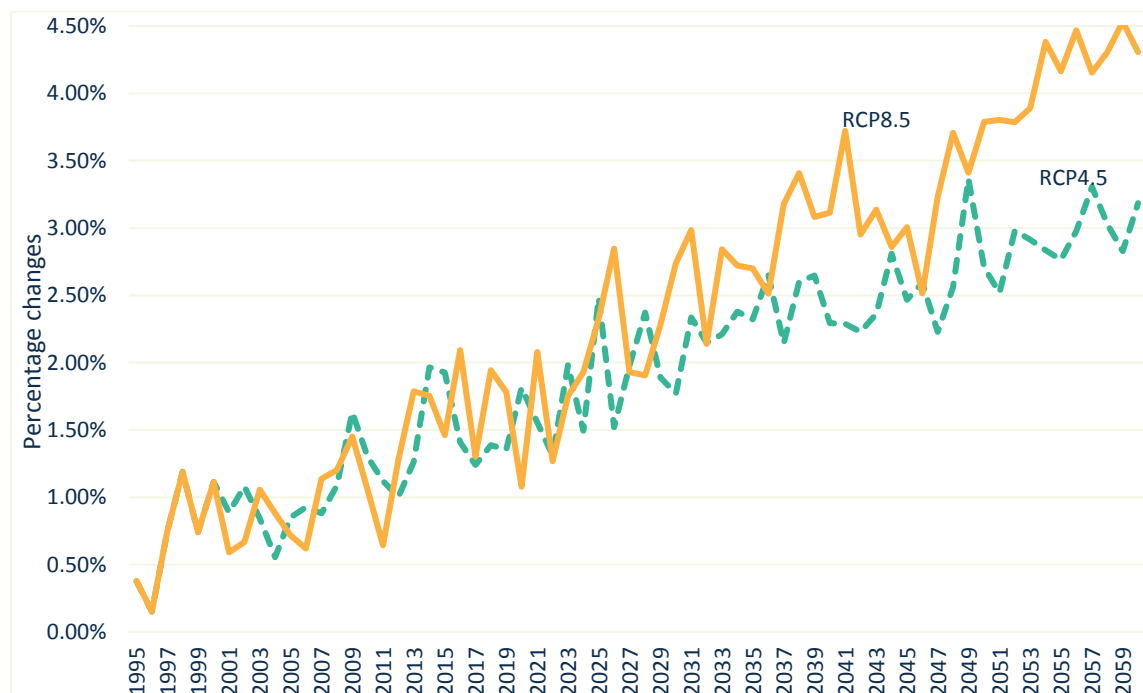


Figure 2: Average losses of national GDP due to climate change



Table 4 shows the average national economic losses/gains due to climate change in South Africa comparing the 2030 and the 2050 horizons. Except in the manufacturing sector, there are no significant differences between the losses in 2030 compared to 2050. Therefore, we chose to continue with the 2030 projection scenarios for the rest of this project.

Overall, there is a one percentage point difference between the RCP4.5 scenario and the RCP8.5 scenario. The main sectors with the highest percentage losses are electricity and gas; forestry; fishery; and agriculture. South Africa would forfeit up to 12.9%, 8.5%, 7.3% and 7.1% of its value added respectively to climate change if no mitigation action is taken. With a mitigation scenario that leads to the RCP4.5, losses in the respective sectors are likely to drop to 10.4%, 6.8%, 6.0% and 5.7% respectively. The manufacturing sector will lose more than 2% of its value added to climate change. The services and the mining sectors will also register losses, though these are small relative to the other sectors (2.5% and 1.9% respectively for the RCP8.5 scenario).

Table 4: National average effects of economic losses of climate change

Sector	Absolute changes (Rmillion)				Percentage changes			
	2030 Horizon		2050 Horizon		2030 Horizon		2050 Horizon	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
<i>Elec. & gas</i>	-3408.38	-4390.52	-3408.38	-4390.52	-10.35%	-12.89%	-10.35%	-12.89%
<i>Forestry</i>	-370.53	-449.56	-370.53	-449.56	-6.79%	-8.47%	-6.79%	-8.47%
<i>Agriculture</i>	-1654.77	-2140.36	-1654.77	-2140.36	-5.70%	-7.14%	-5.70%	-7.14%
<i>Fisheries</i>	-3.54	-5.6	-3.54	-5.6	-5.97%	-7.26%	-5.97%	-7.26%
<i>Manufacturing</i>	-3015.94	-3610.42	-3887.22	-6032.67	-2.25%	-2.77%	-2.89%	-4.16%
<i>Mining</i>	-84.89	-12.2	-84.89	-12.2	-1.50%	-1.94%	-1.50%	-1.94%
<i>Services</i>	-20085.33	-25358.62	-20085.3	-25358.6	-1.98%	-2.49%	-1.98%	-2.49%
<i>Water</i>	214.14	281.6	214.14	281.6	1.78%	2.29%	1.78%	2.29%
All	-28409.24	-35685.66	-29280.5	-38107.9	-4.10%	-5.08%	-4.11%	-5.19%

Value added in the water sector is likely to expand due to climate change. The RCP4.5 scenario leads to an expansion of 1.8%, while the RCP8.5 scenario leads to an expansion of 2.3%. It is plausible that heavy investments will flow to the water sector in the future, following the significant water scarcity that would ensue due to the warming climate.

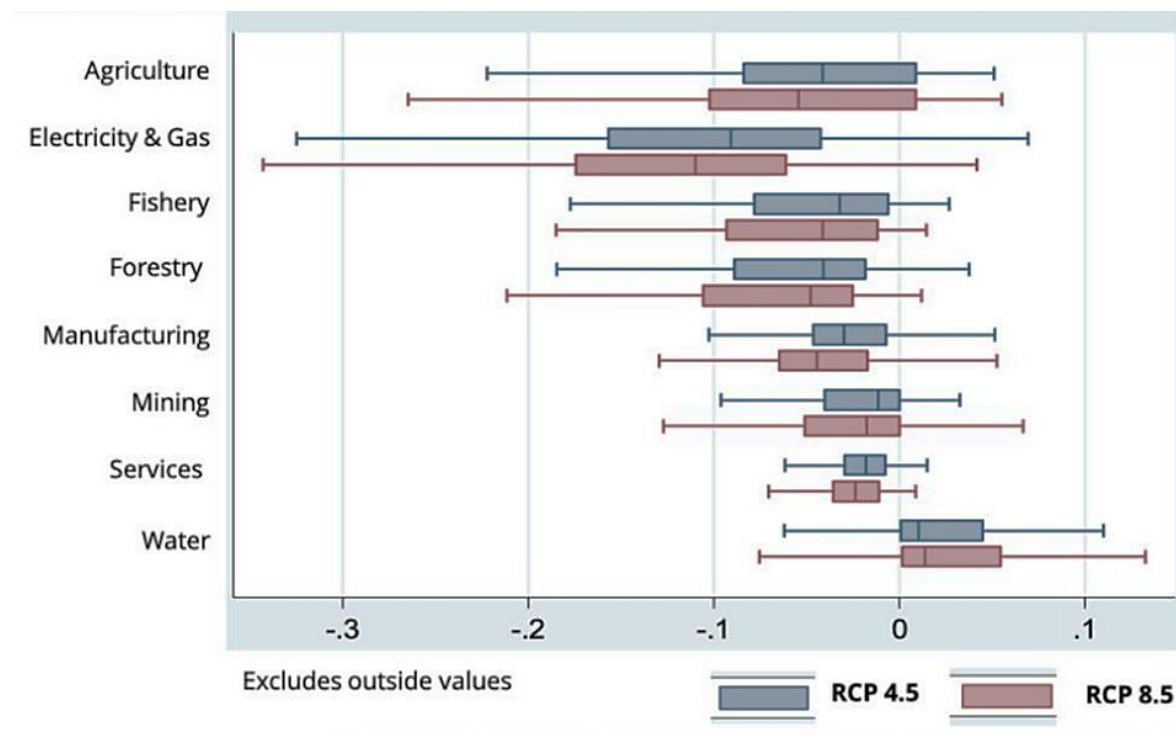


Figure 3: Box plot of the distribution of sector-level effects

However, the projected effects for the different economic sectors and provinces vary a great deal from municipality to municipality. A number of municipalities have a few positive extreme values in all economic sectors. Nevertheless, apart from the water sector, the net effect for all the sectors is negative, resulting in an average negative effect for the respective sectors and the whole economy. From a policy point of view, watershed municipalities are therefore likely to gain economically, while those relying on agriculture, forestry, fishery and electricity and gas are likely to suffer the greatest losses. Policy attention should, therefore, focus on adaptation in these sectors.

At the provincial level (shown in Table 5), the greatest impact of climate change will be felt in Limpopo, where the RCP4.5 scenario will lead to 11% economic losses, while the RCP8.5 will bring about 13% losses. This is in particular due to Limpopo's high dependence on the agriculture, forestry, fishery and electricity and gas sectors in which climate change effects will be more severe in 2050. The next most significantly affected province is Mpumalanga, with its main economic losses predicted to be in the agriculture (15%), forestry (12%), fishery (10%) and electricity and gas (17%) sectors in the case of no mitigation assumptions. There is only a 1% gain overall in Mpumalanga for the RCP4.5 mitigation scenario relative to RCP8.5. It is worth noting that in the Western Cape, the average economic loss is predicted to be 3%, and there is no difference between the RCP8.5 and the RCP4.5 mitigation scenarios. Of greater



concern for this province, are the high relative losses predicted in the manufacturing sector. Most of the provinces record positive effects in the water sector, except for the Western Cape and the Northern Cape who will both be affected negatively in the water sector for RCP8.5, with losses of 7% and 2% respectively. Apart from the water sector, there are a number of other sectors that will be positively affected by climate change. For example, there will be an 8% gain in the mining sector in Mpumalanga due to climate change by 2030 for the RCP4.5 mitigation scenario (for RCP8.5 there will be a 10% gain). The Eastern Cape and Western Cape agricultural sectors will experience a 2% increase related to climate change. In Gauteng, the Free State, and the North West, the manufacturing sector will each expand by 2%. The mining sector will also expand in the Free State and Gauteng by 1% each for the RCP8.5 scenario. In the Western Cape the fishery sector will expand by 1% due to climate change in 2030. The provincial findings suggest again that policy action for adaptation is most important in the agricultural, forestry, fishery, and electricity and gas sectors in most provinces, but particularly in Limpopo, Mpumalanga, and the Free State.

Table 5: Percentage losses/gains: Scenario 4.5 versus 8.5

Province	Agri	Man	Min	Ser	For	Fis	E&G	Wat	All
Scenario RCP4.5									
<i>Eastern Cape</i>	2	-3	-5	-2	-3	-3	-9	1	-3
<i>Free State</i>	-6	2	1	-1	-11	-7	-12	3	-4
<i>Gauteng</i>	-5	1	0	-2	-6	-6	-7	1	-3
<i>KwaZulu-Natal</i>	-5	-3	-4	-2	-4	-5	-11	5	-3
<i>Limpopo</i>	-22	-2	-4	-3	-22	-26	-18	5	-11
<i>Mpumalanga</i>	-13	-3	8	-2	-10	-7	-14	0	-5
<i>North West</i>	-4	2	-1	0	-4	-5	-8	1	-2
<i>Northern Cape</i>	-6	-2	0	-3	-2	-1	-6	-1	-3
<i>Western Cape</i>	2	-8	-2	-2	-2	1	-6	-6	-3
National (%)	-5.70	-2.25	-1.50	-1.98	-6.79	-5.97	-10.35	1.78	-4.10
Scenario RCP8.5									
<i>Eastern Cape</i>	2	-4	-6	-3	-4	-4	-11	1	-4
<i>Free State</i>	-7	2	1	-2	-13	-8	-15	4	-4
<i>Gauteng</i>	-7	2	1	-3	-8	-9	-9	1	-4
<i>KwaZulu-Natal</i>	-7	-3	-5	-2	-6	-6	-14	7	-4
<i>Limpopo</i>	-27	-2	-5	-4	-28	-32	-23	6	-13
<i>Mpumalanga</i>	-15	-4	10	-3	-12	-8	-17	1	-6
<i>North West</i>	-5	2	-2	0	-5	-6	-9	1	-3
<i>Northern Cape</i>	-7	-3	0	-4	-3	-2	-8	-2	-4
<i>Western Cape</i>	3	-9	-2	-3	-3	1	-7	-7	-3
National (%)	-7.14	-2.77	-1.94	-2.49	-8.47	-7.26	-12.89	2.29	-5.08

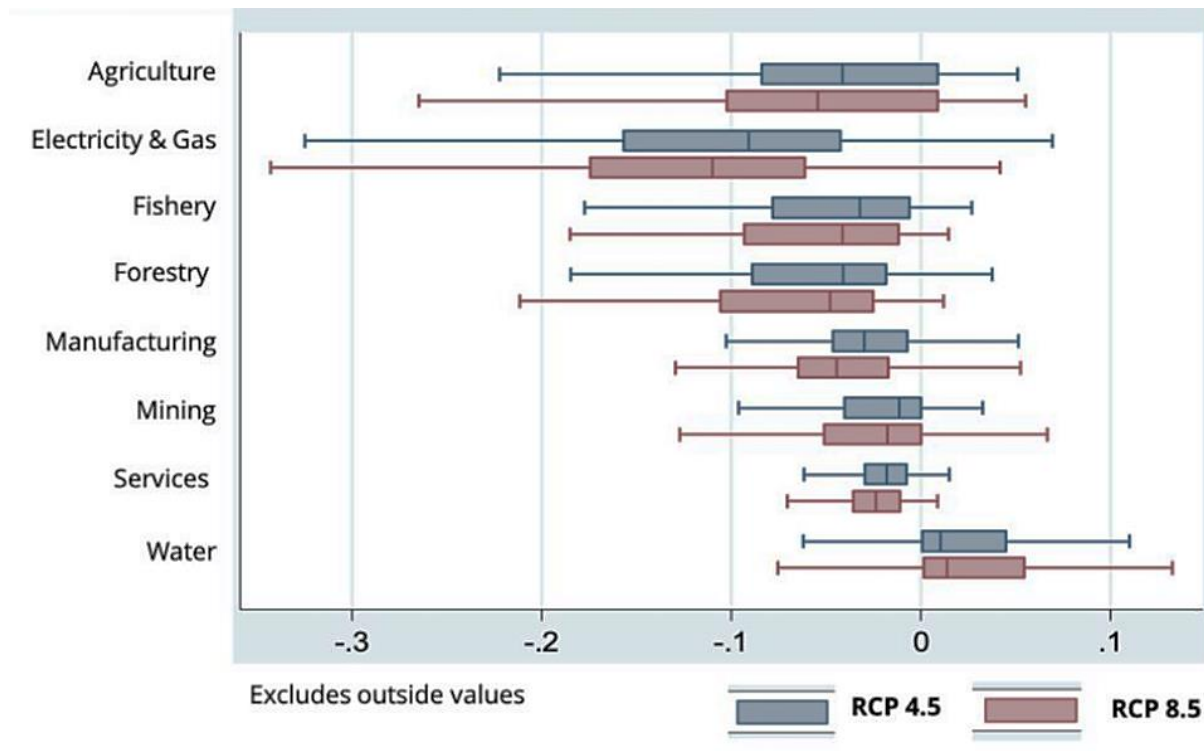


Figure 4: Box plot of the distribution of provincial effects

4.1.1 Key municipal findings

A number of individual municipalities present extreme effects in the positive and the negative sides within specific sectors. The findings in these municipalities are summarised in Figure 5. The most negative impact is in forestry in the Blouberg and Ephraim Mogale municipalities in Limpopo with 50% and 48% losses respectively for the RCP4.5 scenario, and 54% and 47% respectively for the RCP8.5 scenario. In order of decreasing magnitude of losses, key affected municipalities are Mogalakwena in terms of fishery and agriculture, Mutale in agriculture, forestry, and electricity and gas and Thulamela in agriculture and fishery. Other municipalities to earmark for particular attention in adaptation policies are Elias Motsoaledi, Polokwane, Makhuduthamaga, Greater Giyani, and Bela-Bela.



Figure 5: Municipalities with extreme negative and positive effects

Positive effects are projected for a number of municipalities mainly in water and mining. In Kwa-Zulu-Natal, uMfolozi has the highest gains in the water sector, followed by Ulundi, Mtubatuba, and Hlabisa. A number of municipalities are projected to have positive effects in the water sector in Limpopo. These are Ephraim Mogale and Mutale. In Mpumalanga, the most significant positive effects are all in the mining sector for Msukaligwa, Chief Albert Luthuli, Thembisile Hani, Dr JS Moroka, Thaba Chweu, Mkhondo, Lekwa, and Bushbuckridge.

5 RECOMMENDATIONS

Key recommendations in adapting South Africa's settlements to climate change are:

- RCP8.5 will yield significant economic losses.
- Adaptation strategies have to be customised to suit specific socio-economic conditions for a given settlement.
- Settlement design has to take into account spatial inter-linkages in terms of economic activities and anticipated climate change effects. This requires adaptation policy coordination beyond local settlements to involve all spheres of government.
- Careful human capital and skills development planning needs to account for the structural effects of climate change and possible changes in trans-settlement linkages.



Such plans have to be municipality- and/or province-specific, based on the anticipated economic structural changes.

- Adaptation strategies should emphasize those settlements that rely on agriculture, forestry and fisheries.
- Settlements in the Limpopo, Mpumalanga and Free State provinces will be the most vulnerable.
- Settlement adaptation strategies should exploit opportunities that may arise in expanding sectors, such as water in most provinces, and mining in Mpumalanga.

6 CONCLUSION

The projections of the effect of climate change have painted a picture, not only of significant economic losses, but also of the potential to significantly alter economic structure. Certain sectors are projected to expand in certain localities, such as mining in most of Mpumalanga and the water sector in most of the country. However, losses outweigh gains in almost all municipalities in South Africa. The implication of the findings is five-fold. First is that given the international reluctance in committing to mitigation scenarios that will result in significantly low radiation forcings, the most plausible forcing scenario will not be able to avert significant economic losses. Therefore, adaptation strategies have to be put in place as urgently as possible. The longer policy measures take to be implemented, the more losses are incurred as the picture shows that we are already experiencing losses.

Given the varied effects by sector and by geography, adaptation strategies have to be customised to suit specific conditions. Private economic agents may not be able to make socially optimal choices in this regard, hence the need for careful public policy coordination with significant state leadership.

The anticipated changes in economic structure imply that a number of sectors may shed jobs in varying proportions. This highlights the need for careful human capital and skills development planning that accounts for the economic structural effects of climate change. Each municipality and/or provincial government will have to develop such plans based on its anticipated economic structural change.

Climate change adaptable policies have to consider inter-municipal and inter-provincial impacts. Our results suggest significant spatial effects of the impacts of climate change.



Consequently, we suggest that policy measures must transcend cities to involve all tiers of government with seamless coordination in order to deliver effective adaptation policy implementation.

Main population groups to pay attention to in developing adaptation strategies should be those that depend on agriculture, forestry and fisheries in most municipalities in almost all provinces, especially in Limpopo, Mpumalanga, the Free State and the North West. Attention is to be paid to the manufacturing sector in the Western Cape and the Eastern Cape, and to the water sector in the Western Cape.

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