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Economic implications of climate change in Zambia

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About the project

Southern Africa –Towards Inclusive Economic Development (SA-TIED)

SA-TIED is a unique collaboration between local and international research institutes and the government of South Africa. Its primary goal is to improve the interface between research and policy by producing cutting-edge research for inclusive growth and economic transformation in the southern African region. It is hoped that the SA-TIED programme will lead to greater institutional and individual capacities, improve database management and data analysis, and provide research outputs that assist in the formulation of evidence-based economic policy.

The collaboration is between the United Nations University World Institute for Development Economics Research (UNU-WIDER), the National Treasury of South Africa, the International Food Policy Research Institute (IFPRI), the Department of Monitoring, Planning, and Evaluation, the Department of Trade and Industry, South African Revenue Services, Trade and Industrial Policy Strategies, and other universities and institutes. It is funded by the National Treasury of South Africa, the Department of Trade and Industry of South Africa, the Delegation of the European Union to South Africa, IFPRI, and UNU-WIDER through the Institute's contributions from Finland, Sweden, and the United Kingdom to its research programme.

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ABSTRACT

This study uses an integrated approach to analyse the impacts of climate change on Zambia's electricity supply and general economy, considering two global climate policy scenarios: Unconstrained emissions (UCE), without effective policies to limit emissions of greenhouse gases; and Level 1 stabilisation (L1S) where aggressive emission reduction policies are implemented. These impacts are captured through three channels: agriculture, roads and energy. The analysis focuses on the projected outcomes for the period between 2045 and 2050. To effectively capture the economy-wide impacts, a dynamic computable general equilibrium model is used.

The study concludes that real output growth is adversely affected by climate change under both scenarios. While growth is negatively impacted by all the channels, the roads channel introduces the most uncertainty, because of the importance of roads (and generally infrastructure) in Zambia's economy. The analysis suggests that climate change in the absence of mitigation policies would reduce Zambia's GDP by about 6% by 2045-50, while under the L1S scenario the impact could at worst be 4% for the same period. These average results show that Zambia's real annual GDP growth rate would decline between 0.02 and 0.04 percentage points because of climate change. More favourable outcomes of the L1S scenario notwithstanding, the trade balance under L1S scenario increases more than under the UCE scenario.

At the sectoral level, electricity and agriculture are the most affected. Unlike the roads channel, the impact of shocks that came through the energy channel were minimised and contained by increasing electricity imports. Without these, the impacts of the energy channel would even be worse than the roads channel. This brings to the fore two policy issues: the need to invest in climate-resilient electricity-generating technologies, and the importance of clear electricity trade policy.

Keywords: uncertainty, economic growth, mitigation, adaptation, electricity supply

1 INTRODUCTION

Climate in the Southern Africa region is projected to change: temperatures will rise, and the frequency and intensity of extreme events such as droughts and floods will increase. Evidence suggests that these changes will have significant negative impacts in the region, although the degree of impact would vary from one country to another. It is expected that the poorest will be the most affected, as they lack adaptive capacity. Such an assessment led the Stern Review Commission to recommend that all countries should incorporate climate change measures in their development policies, plans and strategies (Stern, 2007).

Despite this recommendation, there has been limited research to inform government policy in Southern Africa about climate adaptation measures. This paper therefore aims to generate knowledge for effective policy decisions. The fundamental strategic decisions in the near term, such as basic infrastructure investments, will influence the pace and character of socio-economic development as well as the potential vulnerability of the society to the implications of climate change. This work builds on studies conducted under initiatives such as "Development under climate change"; "Regional growth and development in Southern Africa", and "Africa's energy futures".

The impacts of climate change are analysed using an integrated approach. This approach takes into account the back and forward inter-linkages from the climate system to the bio-physical system, through to the socio-economic system, at global level. It uses internally consistent scenarios and inputs that take into account global climate science (what climate change outcomes are expected?); biophysical outcomes (what does climate change mean for sensitive elements of society and the natural environment?); and socio-economic analysis (what are the policy options and trade-offs?).

The paper has two key objectives: firstly, to understand the potential impacts of different climate change channels (agriculture, roads and energy) on economic growth in Zambia, at the national level, by considering the impacts on various sectors in the economy; secondly, to assess the implications of these impacts for climate adaptation policy in the country. These objectives will be achieved by answering the following questions:

1. Which climate change channels have the largest impacts on GDP growth in Zambia and why?
2. What is the impact of climate change on hydro-power production potential? What does the impact on hydro- power production potential mean for electricity (supply and price) in Zambia and where it is sourced? What policy implications does this have? Is there a role for renewables?
3. Which sectors are the most affected and which benefit?
4. What non-agriculture adaptation policies are suggested by the modelling?

Overall, the paper will contribute to answering the question: What are the implications of climate change for strategic development decisions in Zambia by 2050?, through the Systematic Assessment of Climate REsilient Development (SACRED) framework (Sokolov et al., 2005; Strzepek et al., 2011; Fant et al., 2012; Paltsev, 2012; Diao and Thurlow, 2012). The paper also provides policy recommendations for the development of a sustainable, robust and climate-resilient economy.

2 BACKGROUND AND LITERATURE REVIEW

This section gives a background and literature review of Zambia's energy sector and the general economic structure. It focuses on the impacts of climate change on the energy sector and the economy.

2.1 Zambia's economic structure and linkages

Since Zambia's independence in 1964, its economy has largely depended on copper mining. This remains the case 55 years on, despite attempts by successive governments to re-focus policy towards industrializing and diversifying the economy. Copper dominates exports, accounting for around 70% of foreign exchange earnings.

The mining sector is also an important contributor to employment, providing 56,227 direct jobs in 2005 and 82,725 in 2014 – an increase of 41%; as well as thousands of indirect jobs in ancillary services. This dependence on the mining industry implies that Zambia's economy is highly susceptible and sensitive to world commodity price fluctuations and change in climatic conditions such as drought, due to the dominance of hydro-power in Zambia's electricity supply. To elaborate, in 2015, the copper output target was 800,000 metric tonnes but the realised output was 711,000 metric tonnes (GRZ, 2017, MMMD, 2018). This was largely attributed to low copper prices and power shortages.

The manufacturing sector is another important economic sector in Zambia. Its contribution to GDP averaged 7% for the period 2010 to 2017, providing 223,681 jobs in 2014. Its role in economic growth cannot be downplayed as it creates backward and forward linkages in the economy. However, as with the mining sector, energy deficits resulting from climate variability (reduced rainfall) weighed down productivity in the manufacturing industry by 60–70%. Vulnerability to climate change also extends to the services sector, where tourism could be the most adversely affected, and, consequently, adjunct line businesses (MNDP, 2016; GRZ, 2017; ZamStats, 2020).

Agriculture is another critical sector in Zambia's economy. Although its contribution to GDP has reduced over the past decade, it remains the largest employer, with over 60% of the population employed in the sector. With only 15% out of 47% of Zambia's arable and fertile land surface under cultivation, the agricultural sector is one of the government's earmarked sectors for economic diversification. The decrease in sector productivity and contribution to GDP has largely been attributed to worsening and erratic climatic conditions (MTENR, 2011; MNDP, 2016; GRZ, 2017, World Bank, 2020). This decrease translates to worsened state of household welfare and livelihoods, particularly for rural households.

After an impressive decadal (2004–14) economic growth rate averaging 7.4% per year, Zambia attained middle-income country status in 2011. The unprecedented growth during this period was largely spurred by high copper prices. However, this growth benefited only a small segment of the urban population and had limited impact on poverty, as Zambia's national poverty (estimated at 54.4% in 2015)[1] and inequality remains stubbornly high. Since the 2015 economic downturn, Zambia has continued to experience persistent macroeconomic imbalances and declining growth rates. The most recent estimates show that the Zambian economy grew by 3.7% in 2018 compared to 3.5% in 2017 (World Bank, 2019). The slight increase in growth for 2018 reflects strong performance of services (in particular wholesale and retails, pensions, and information and communication). Yet, faster recovery continues to be undermined by a number of factors: lower crop harvest as agricultural sector growth has remained negative; a growing electricity supply crisis; and the country's weakening fiscal position.

Based on the current growth trajectory, Zambia's economic performance seems to correlate with climate variability, as can be seen by the occurrence of major economic downturns. This could, in part, be attributed to Zambia's high degree of dependency on agriculture and natural resources, both of which are climate-sensitive sectors. Extreme weather events such as floods and droughts are already happening and are expected to increase in intensity and frequency (Arnell et al. 2003; Tadross et al. 2005; van Vliet et al., 2016). These events have, in the last three decades, cost Zambia some 0.4% of annual economic growth (Thurlow et al., 2009).

Climate-induced changes to physical and biological systems are already exerting considerable stress on the country's vulnerable sectors. Given the climate predictions and associated vulnerabilities, it is critical to understand the scope and breadth of the economic impacts of climate change as it relates to the Zambian economic environment. As pointed out by Wade (2015), one of the most profound implications of climate change may be its negative effect on economic growth in the long run: global warming will primarily influence economic growth through damage to property and infrastructure, lost productivity, mass migration and security threats. Zambia's actual growth trajectory will then depend on both the adaption and mitigation options available and

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[1] A detailed poverty analysis in Zambia can be found in CSO (2016).

the efficiency of its practices and policies (Arndt and Tarp, 2015). To put this into perspective, on average, climate variability reduces Zambia's GDP growth rate by 0.4 percentage points per year, which costs the country USD 4.3 billion over a ten-year period (Thurlow et al., 2009). Furthermore, as Mendelsohn (2013) notes, lack of immediate, aggressive and inefficient mitigation climate change policies poses the biggest threat to economic growth. For example, past climate mitigation efforts mainly focused on developed countries, but Field et al. (2014) observe that to effectively mitigate the impacts of climate change, middle-income developing countries, including Zambia, need to participate in a global mitigation effort.

2.2 Impact of climate change on the energy system

As Cronin et al. (2018) show, all aspects of the global energy system will be impacted by climate change. For instance, the rising temperatures have implications on the demand patterns for heating and cooling in the commercial, industrial and residential sectors. Also, increase in temperature translates to increased irrigation demand, hence increased energy demand from the agriculture sector. Similarly, van Vliet et al. (2016) found that the impacts of climate change on the supply side of the energy system are far-reaching. While reduced availability of water resource is usually thought to only affect hydro-power plants, it also impacts thermal plants, as there would be limited amounts of water for cooling. Reduced cooling translates to reduction in performance efficiency of the plant, which implies reduced output. Furthermore, increased temperature means increased water temperature, which has significant implications on the performance efficiency of thermal plants be they coal, heavy fuel oil, or nuclear.

Further, van Vliet et al. (2016) find that at global level, output from both hydro and thermal power plants, which account for 98% of the world's electricity production, would reduce by more than 60% as a result of climate change from 2040 to 2069. This projected reduction is largely attributed to reduction in water availability and rising temperature, as explained above. On the other hand, Hamududu and Killingtveit (2012) and Turner et al. (2017), project that the impact of climate change on hydro-power, at global level, will be limited. However, both these papers, as well as Turner et al. (2017), agree that output from hydro-power plants in Southern Africa will reduce. This agreement notwithstanding, the estimated magnitude of climate change impacts in the region and indeed Zambia, is varied. This highlights the importance of analysing how climate change might impact Zambia's hydro-power production, so that the electricity sector can be made more climate-resilient and adaptive: electricity is an enabler and a key input to economic growth.

2.3 Zambia's energy supply system

As in many countries worldwide, Zambia's energy sector, particularly the electricity sector, is extremely vulnerable to climate change and variability, particularly given that 85% of the country's 2,827 Megawatt (MW) installed capacity is hydro. Despite its vulnerability, the electricity sector has been identified as a key driving force for economic development; it is critical to the country's industrialisation activities.

The climate change threat to Zambia's hydro-power dominated electricity vis-a-vis its economic growth is, then, clear. As observed by various studies (Tembo, 2012; Nakhooda et al., 2013; Spalding-Fecher et al., 2017), Zambia's hydro-power production is susceptible to droughts, which implies that the whole economy is also vulnerable to climate variability shock. Furthermore, lack of access to clean energy leads to increased consumption of firewood and charcoal, which exacerbates deforestation, and this in turn reduces the river run-off needed for sustainable hydro-power generation[2] (Ebinger and Vergara, 2011; Hamududu and Killingtveit, 2012; WMO, 2015; CSO, 2016). For instance, as Bowa-Mundia et al. (2019) note, the droughts witnessed in 2015/16 and 2018/19 led to the failure of Zambia's electricity sector to generate the electricity required to sustain economic growth. It is estimated that, as a result of the 2018/19 drought on top of the already existing

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[2] In 2015, over 80% of Zambian households were using either charcoal or firewood for their cooking energy needs (CSO, 2016).

electricity supply deficit, Zambia's economic growth slowed down considerably, to about 2% in 2019. This was far lower than the average growth rate of 4.6% recorded over the period 2011 to 2018 (Bowa-Mundia et al., 2019). Similar impacts that climate change and variability would have on the economy are also highlighted in the National Policy on Climate Change (MNDP, 2016).

Electricity

As stated above, Zambia's electricity sector is predominantly hydro, with coal (300 MW), heavy fuel oil (105 MW), diesel (89 MW) and solar (0.06 MW) contributing only 15% (ERB, 2019). These figures highlight two things: the noticeable role that carbon-emitting technologies play, and how low the contribution of solar, a renewable energy source, is to the total national energy mix. In addition, to highlight another climate vulnerability, 90% of the hydro-power capacity generation mix is from just two projects – Kariba North and Kafue Gorge, located in the country's south. With projected frequency and intensity of drought in the country's southern part, it is expected that Zambia's electricity sector would face significant challenges. For instance, Fant et al. (2015) found that hydro-power generation in Zambia could reduce significantly. The decrease is attributed to the decline in run-off in the western area of Zambia, upstream of most of the hydro-power plants.

Petroleum

Zambia is self-sufficient in all her energy requirements save for petroleum, which is one of the country's most important imports (Tembo, 2012). Petroleum contributes a crucial 9% to the nation's total energy requirements. It plays an important role in powering Zambia's economy particularly in the agriculture, transport, and mining sectors. Therefore, an increase in world oil prices would have ramifications on the operations of the transport and mining sectors. According to the Zambia Development Agency, the demand for petroleum products increased by about 100% over a period of six years (2007-2013), with a progressive increase in consumption to 618,441 metric tons in 2018 (ZDA, 2013; ERB, 2019).

Coal

Zambia's current proven coal deposits are located in the Southern Province and are estimated at about 80 million tonnes (ERB, 2019). Currently Zambia only has two coal mines - the major one being the formerly government-owned Maamba Collieries Limited, and the other being Collum Coal Mine. With the regional power deficit, coal is emerging as a major source of power generation, especially with improved and more efficient generation technology (Power Africa, 2017).

Solar

Zambia has an average of 2000-3000 hours of sunshine per year, but solar penetration has remained relatively low, due to the technology's high initial costs. As a result, Zambia solar utilization is dominated by donor-funded projects, government, non-governmental organizations, and mission institutions for schools' clinics. The World Bank Group is currently the largest single financing agency of photovoltaic (PV) development in Zambia, through its involvement in the scaling solar project.

Biofuels

The government is currently exploring ways to develop the biofuels industry in Zambia. Other than addressing the need to reduce the impacts of fossil fuels on the environment, the government hopes that this sector would help improve security of energy supply, reduce oil price shock, and improve the livelihoods of many families involved in agriculture. Sinkala et al. (2013) note that the capacity to produce biofuels in Zambia exists. However, due to the infancy of the industry in the country, productivity and crop husbandry techniques are still largely in the initial stages (Samboko et al., 2017). Furthermore, the impact that climate change would have on potential energy feedstock in Zambia is not well understood, nor analysed. However, development of the biofuels industry would lead to other trade-offs, such as increased water demand for irrigation for biofuel feedstock production versus water for hydro-power production.

3 METHODS

3.1 Overview of the SACRED analytic framework

The general framework employed in this research is the Systematic Assessment of Climate REsilient Development (SACRED) framework. This is a chain of modelling analytic tools that look at changes in global systems from the climate system through to local economic systems. The global climate model explicitly captures all the earth and climate science dynamics on a global scale (Sokolov et al., 2005). Output of this global model is fed into other bio-physical models. Which consider, among others, how climate change would impact global prices (Paltsev, 2012), crop yields (Fant et al., 2012), river run-off (Strzepek et al., 2011), and infrastructure (Chinowsky et al., 2015). The outputs of these bio-physical models are fed into the socio-economic model. This type of model (in this case, a computable general equilibrium (CGE) model) is used to analyse the impact of climate change on the economy. The details of the CGE model implementation used in the SACRED framework can be found in Diao and Thurlow (2012). Examples of other publications that used this framework are Arndt et al. (2011), UNU-WIDER (2012), Schlosser and Strzepek (2013), and Cullis et al. (2015).

The SACRED framework is part of the integrated global systems model (IGSM) framework (see Sokolov et al. (2005), Sokolov et al. (2009) and Webster et al. (2012) for details). The IGSM has three main components (Arndt et al., 2019):

1. climate and Earth system component: coupled dynamic and chemical atmosphere, ocean, land, and natural ecosystem interactions and feedbacks;
2. land ecosystems and biogeochemical exchanges component, within a global land system framework, for analysis of the terrestrial biosphere; and
3. economics, emissions, and policy cost component for analysis of human activities, including policy measures, as they interact with climate processes.

As would be expected, being a global model, the IGSM generates many future climates, so the outputs of the need to be downscaled for easier analysis at country and regional levels. The initial output of the IGSM gave 6,800 regional future climates, which were reduced to 426 and 398 for UCE and L1S policy scenarios respectively. This sub-sample of future climates represent a good understanding of the range and likelihood of potential climate change for Southern Africa in general and Zambia in particular (Arndt et al., 2012a; 2012b). Furthermore, whereas other analytic papers on the impacts of climate change in the Southern Africa region focus on limited possible future climates, this research programme under the SACRED framework provides for a comprehensive analysis of climate uncertainty in the region. The formal treatment of uncertainty on biophysical and economic outcomes enhances policy analysis and, consequently, development planning (Arndt and Thurlow, 2013).

Figure 1 shows the integrated modelling framework employed to analyse the impacts of climate change on Zambia's economy. The framework begins with changes in climate outcomes (derived from general circulation models) of the Earth, oceans, and atmosphere. These changes are passed on a series of bio-physical models to assess the impacts of changes in climate outcomes on precipitation and temperature. By understanding the impacts on the bio-physical, the impacts on the economy can be analysed, using a CGE model. The three impact channels considered in this analysis are agriculture, roads and energy (see Table 1). In addition, focus is given to the two policy scenarios previously characterized.

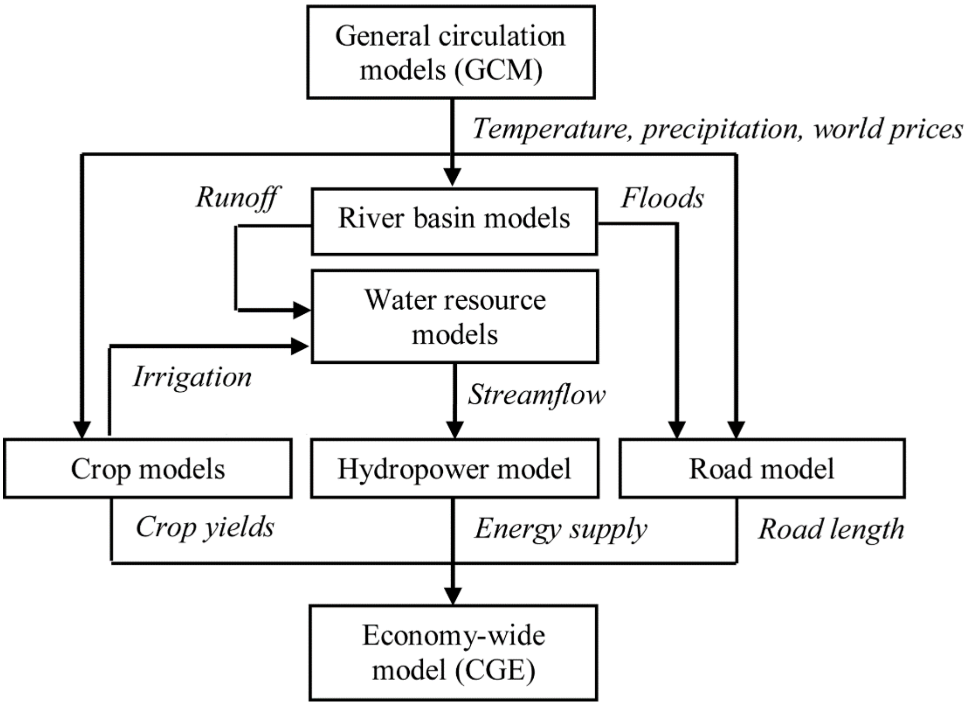

Figure 1: General modelling framework (Arndt et al., 2014)

3.2 Economy-wide model

The economy-wide (CGE) model takes outputs of the bio-physical systems (as described above) and simulates the impacts that these might have on the economy. To analyse the impact of climate change on the economy, key impact channels (i.e. agriculture, roads, and energy) are used. For example, using these channels, the projected reduction of hydro-power production can be analysed. Furthermore, the ripple effect of this reduction in hydro-power production on the manufacturing sector can also be analysed. The benefits of using a CGE model are given in Arndt and Thurlow (2015). They can be summarised as follows: it is possible to simulate the functioning of a market economy; it is possible to isolate and consider aspects of the economy that can be directly impacted by climate change; and the models assure that all economy-wide constraints are respected.

The CGE model used in the paper was calibrated to a 2007 social accounting matrix (SAM). It includes three macroeconomic accounts: government balance, current account, and savings-investment account. Ordinarily, CGE models are built as static models. However, to effectively capture the impact of climate change over time, it was necessary to make it dynamic through a set of accumulation and updating rules, such as investment adding to capital stock (endogenous) and productivity growth (exogenous) over time. For more details of how the CGE model was implemented see Chinowsky et al. (2015), Arndt et al. (2012a), Chinowsky and Arndt (2012), and Diao and Thurlow (2012).

4 RESULTS

This section presents results of the analysis. Primarily, results will be split into Unconstrained Emissions (UCE) and Level 1 Stabilization (L1S) global policy scenarios. These policy scenarios are extremes, UCE is a do nothing type of scenario while L1S is a more preferred scenario, closer to the Paris Agreement levels of aspiration. A summary of the scenarios, which are also referred to as impact channels (Baseline, Agriculture, Roads and Energy), used in this analysis is given in Table 1 below, based on Arndt and Thurlow (2015).

Table 1: Economy-wide modelling scenarios

Scenario	Description
Baseline	This scenario assumes changes in world prices and considers historical climate variability. However, no changes in climate are considered. It is a counter-factual scenario to those that take climate change into account.
Agriculture	On top of baseline, the scenario assumes climate change implication on agriculture production. Uncertainty in climate change is captured using 426 future climates.
Roads	On top of agriculture, the scenario adds impacts of climate change on roads.
Energy	On top of roads, the scenario adds the impacts of climate change on hydro-power generation.

4.1 Main biophysical outputs outcomes in 2045-2050

The sub-section gives results that focus on the changes in temperature and precipitation relative to the baseline; and then briefly discusses them. The two variables (temperature and precipitation) were exogenous inputs into the CGE model, which were outputs from other models shown in Figure 1 above. However, even though they are exogenous, they are consistent with future climates and policies used in analytic framework.

Figure 2 shows the expected rise in average temperature for 2045–2050[3] for the warmest month of the year for all the 398 and 426 future climates under L1S and UCE respectively relative to the baseline.[4] On average, temperature across Zambia is expected to rise by about 1.83 °C and 1.08 °C for UCE and L1S policy scenarios respectively by 2050.[5]

While temperature increases under all future possible climates, precipitation is more varied. Figure 3 shows the precipitation outcomes for 2045–2050.[6] As can be seen, precipitation is more uncertain under UCE than under the L1S scenario. This means that, under the UCE policy scenario, Zambia is expected to experience both increased rainfall and increased drought spells. This would make it significantly challenging for the government to develop a robust adaptation strategy that caters for both extremes of precipitation. To highlight the certainty between the two policies, under the UCE scenario the standard deviation of changes in precipitation is 5.72% while under the L1S scenario it is 3.24%. Overall, precipitation under the UCE scenario is expected to reduce, while under the L1S scenario it is expected to increase (the skewness is -0.27 and 0.046 under the UCE and L1S scenarios respectively).

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[3] In order to minimize the influence of a particular year, we consider the average from 2045 to 2050. Furthermore, a ratio greater than one implies that climate change has a positive effect while a value less than one implies that climate change has a negative effect.

[4] In the Figure, the horizontal axis describes the range of possible values for the outcome under consideration while the vertical axis describes a measure of likelihood.

[5] During this same period, the range of possible temperature increase runs from 0.90 to 3.09 and 0.45 to 1.84 for the UCE and L1S policy scenarios respectively.

[6] Changes in precipitation are measured as percentage change in annual precipitation relative to the baseline.

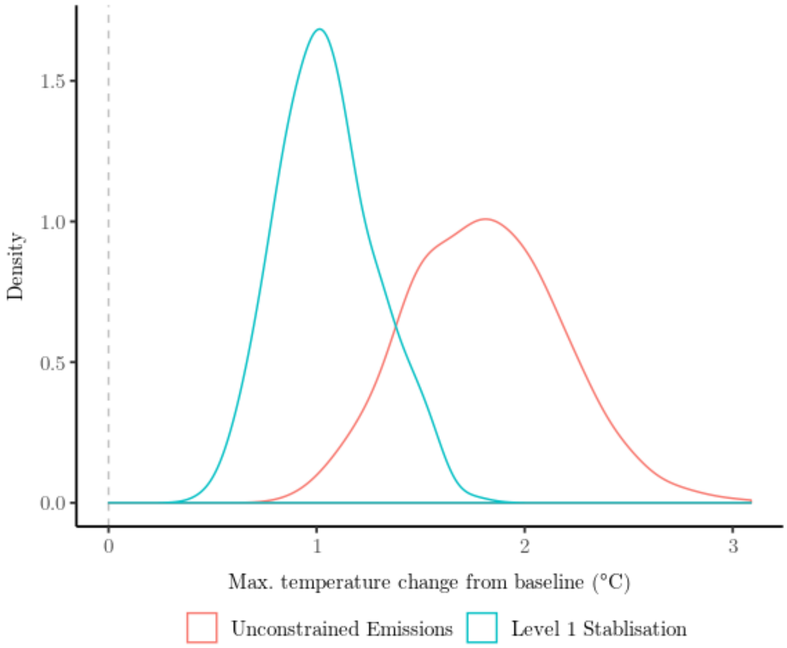

Figure 2: Increase in maximum monthly temperature relative to the baseline

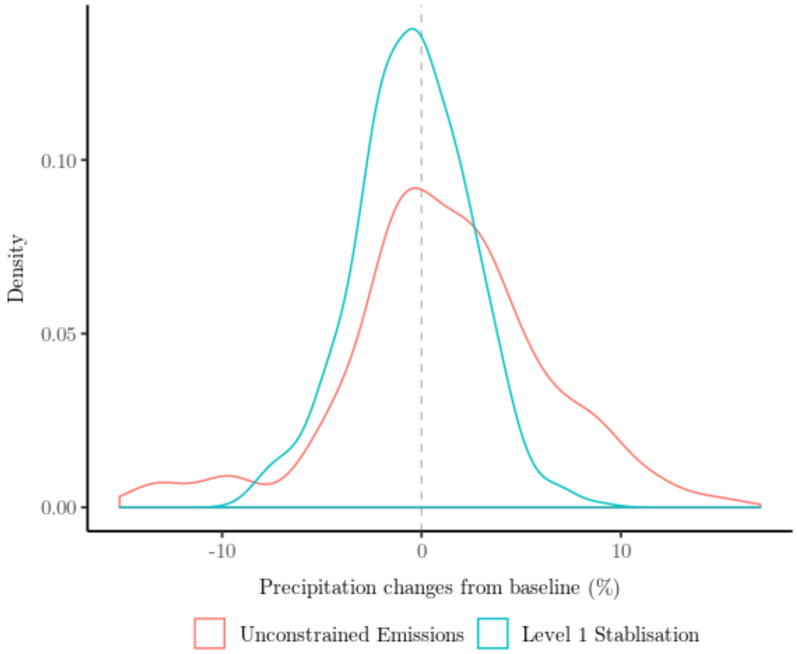

Figure 3: Changes in annual precipitation due to climate change relative to the baseline

4.2 Energy implications

This sub-section presents the results for the impact of climate change on electricity production in Zambia and consequently the policy implications of these impacts. Of the two main commercial energy forms (electricity and petroleum), this sub-section focused on the electricity sector because electricity is produced locally while petroleum is imported.

As mentioned earlier, Zambia's electricity supply is dominated by hydro-power. Figure 4 shows the impacts that climate change has on the electricity sector. It can be seen that this sector is the most affected in terms of production, when all the three channels/shocks are considered (under the Energy shock). The impacts of climate change on the sector are also the most uncertain compared to other sectors, as shown in Table 2 (in sub-section 4.4). Furthermore, these impacts of climate change are more pronounced under the UCE policy scenario. The detailed analysis of how climate change affects all economic sectors is given in sub-section 4.4.

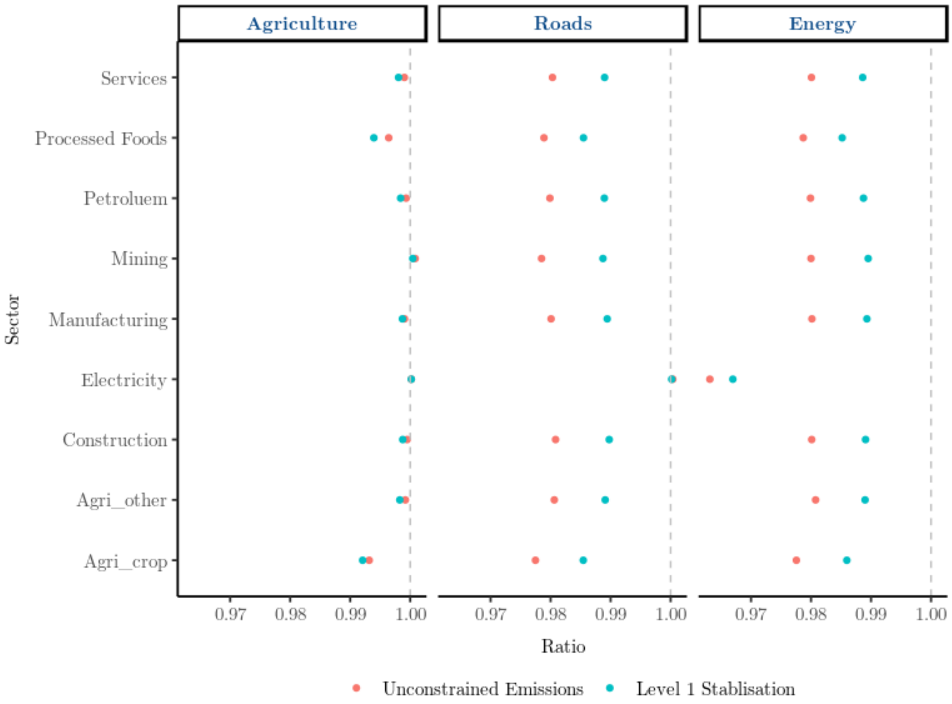

Figure 4: Average change in sector production due to climate change relative to the baseline (average for 2045–2050)

Changes in hydro-power production relative to baseline is given in Figure 5, by policy scenario. Similar to precipitation, changes in hydro-power production under the UCE scenario are more uncertain when compared to the L1S policy scenario. However, hydro-power generation is, on average, expected to reduce more under the L1S scenario than under the UCE policy scenario. That notwithstanding, the uncertainty under the UCE implies that it is more challenging to plan under the UCE scenario than L1S. Compared to the findings of Fant et al. (2015), these results of deviation from the baseline in hydro-power production are more uncertain.

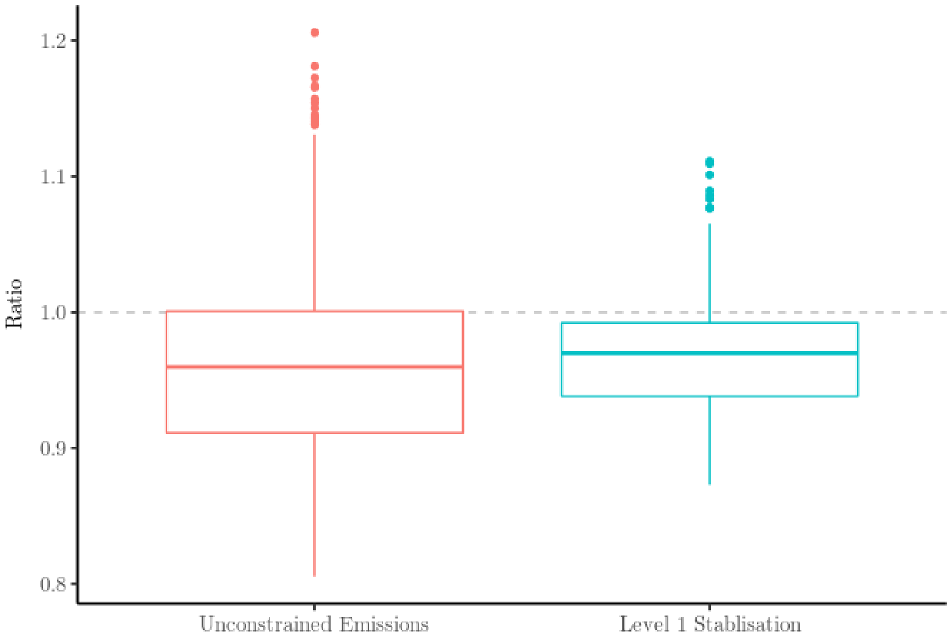

Figure 5: Changes in hydro-power generation due to climate change relative to the baseline (average for 2045–2050)

These changes in production, however, do not have significant impacts on GDP (which is discussed in sub-section 4.3 below), as Zambia increases its electricity imports from the Southern Africa Power Pool regional market. In addition, not only will climate change lead to increased importation of electricity, it is projected that electricity importation will have the second most variance after processed foods.[7] At policy level however, this means that Zambia needs to explore electricity supply options that are climate-resilient: investing in climate-resilient technologies and trade. Such options would be to increase investment in solar technologies (an environmentally friendly option) or development coal technologies (which are carbon-emitting). Other than such investment, electricity importation variation also suggests that Zambia needs to explore trade options for electricity from the regional market. This is particularly important because Zambia plans to be a net electricity exporter and electricity trading hub by 2025. Similarly, Tembo (2018) found that trade and investment in climate-resilient technologies are important in ensuring reliable supply of electricity in Zambia. These two options could also help reduce the price shocks that would result from climate change and variability.

4.3 Macroeconomic implications

This sub-section gives the impacts of climate change on Zambia's GDP.[8] By using the outputs of an economy-wide model (a CGE model) which is influenced by the exogenous inputs such as changes in global prices and electricity mentioned in the preceding sub-sections, the impact of climate change on the GDP, as the macroeconomic indicator, was calculated. Under the baseline impact channel (described in Table 1 above), real GDP at factor cost grows at an average annual rate of 4.8% from 2007 to 2050. GDP growth is expected to peak at 5.5% in the period 2030–2034, then slow down to 5.0% by 2045–2050 period. The GDP share of the agriculture sector is expected to reduce from 13.8% in 2007 to about 11% in 2045–2050. Figure 6 shows the overall impacts of climate change on GDP at factor cost in the period 2045-2050, relative to the baseline channel. It can be seen

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[7] This is shown in Figure 12, in Appendix A.

[8] See Appendix B for indicative results of the impact of climate change on exchange rate and inflation.

that Zambia’s GDP is expected to reduce as a result of climate change – by more under the UCE policy scenario than under the L1S scenario. The uncertainty under the UCE and L1S scenarios are 1.32% and 1.13% respectively.

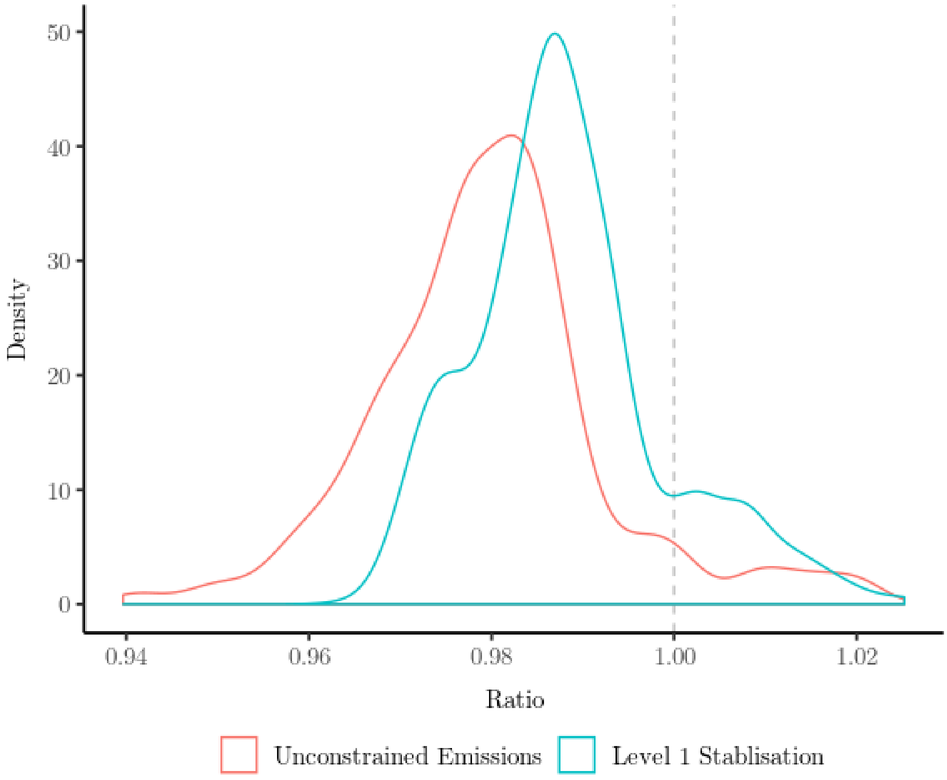

Figure 6: Changes in real GDP at factor cost relative to baseline due to climate change, by policy scenario (2045–2050)

Figure 7 shows the breakdown by impact channel of climate change (given in Table 1 above). As mentioned above, GDP is expected to reduce as a result of climate change in both policy scenarios. The implications of climate change for GDP under the agriculture channel may be positive or negative; however, the bulk of climate outcomes result in decreases in overall GDP. The variance of GDP when only the agriculture channel is considered is relatively low under both the UCE and L1S policy scenarios. It can also be seen from Figure 7 that much of the uncertainty and reduction in GDP growth comes from the roads channel (which consists of the impacts of both the agriculture and roads channels, relative to the baseline), with the UCE scenario showing more uncertainty than the L1S. Details of the sectors impacted by roads channels are given in sub-section 4.4. Of the three impact channels, the one with the least uncertainty is energy.[9] This is because even though local electricity production is the most affected by climate change, electricity supply is not significantly affected as Zambia imports its electricity from the regional market.

As explained by Chinowsky et al. (2013), Arndt et al. (2014) and Arndt and Thurlow (2015), the roads channel is connected to all aspects of the economy. Therefore, changes to it have multiple ripple effects across all economic sectors. Furthermore, as the climate changes, events that lead to deterioration of infrastructure increases, and

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[9] This can be calculated by taking into account the relative impacts on the roads and energy channels.

to replace or maintain the lost infrastructure, spending on infrastructure (via roads channel) would have to increase. This reduces economic growth as investment is pulled away from other growth-enhancing activities.

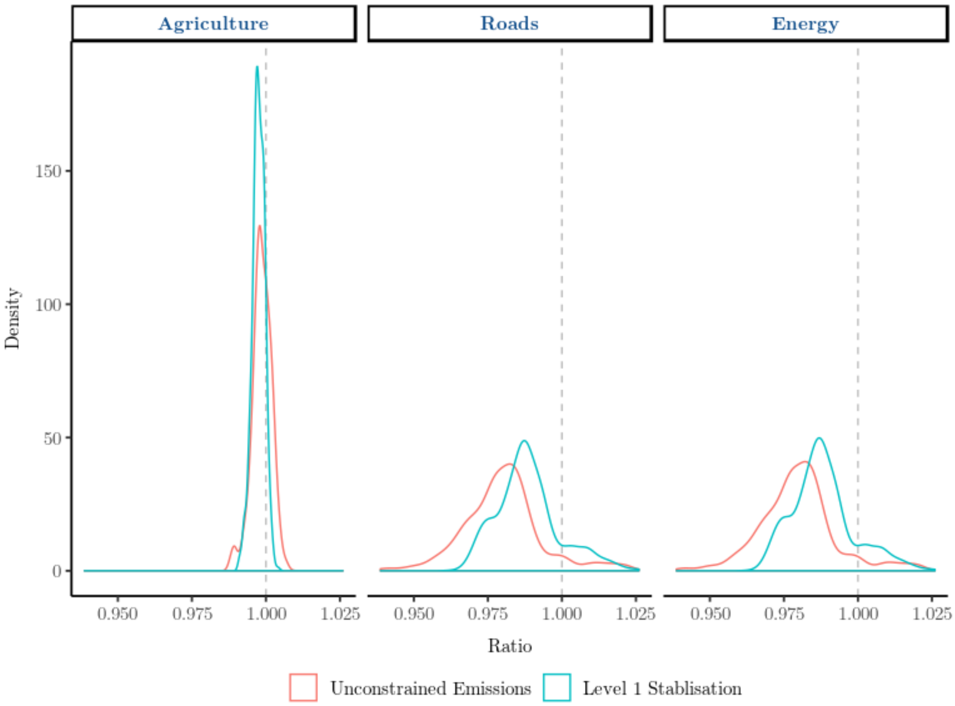

Figure 7: Changes in real GDP at factor cost relative to baseline due to climate change by policy scenario (for 2045–2050)

4.4 Sector analysis

This sub-section gives an analysis of the impacts of climate change on the sectors' value addition and production. The analysis aims to understand how climate change will affect different sectors of the economy under the agriculture, roads and energy channels. Table 2 gives the impacts of climate change on each sector, for both value addition and production for the period 2045–2050.[10]

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[10] Note that the climate change impacts are marginal effects, as the influences of confounding factors in the government sector, households and businesses sector (saving-investment) and external economy (current account) have already been controlled for within the model.

Table 2: Impact of climate change channels on Zambia's economic sectors (2045-2050)

		Value Addition				**Production**			
		Unconstrained emissions		Level 1 stablisation		Unconstrained emissions		Level 1 stablisation	
Channel	Sector	Avg. Ratio	Std. Dev.	Avg. Ratio	Std. Dev.	Avg. Ratio	Std. Dev.	Avg. Ratio	Std. Dev.
Agriculture	Agri_crop	0.99	0.0132	0.99	0.0076	0.99	0.0132	0.99	0.0073
	Agri_other	1.00	0.0025	1.00	0.0016	1.00	0.0027	1.00	0.0017
	Construction	1.00	0.0017	1.00	0.0011	1.00	0.0017	1.00	0.0011
	Electricity	1.00	0.0003	1.00	0.0002	1.00	0.0003	1.00	0.0003
	Manufacturing	1.00	0.0029	1.00	0.0017	1.00	0.0028	1.00	0.0017
	Mining	1.00	0.0009	1.00	0.0008	1.00	0.0009	1.00	0.0008
	Petroleum	1.00	0.0023	1.00	0.0014	1.00	0.0023	1.00	0.0014
	Processed Foods	1.00	0.0092	0.99	0.0058	1.00	0.0092	0.99	0.0058
	Services	1.00	0.0027	1.00	0.0018	1.00	0.0028	1.00	0.0018
Roads	Agri_crop	0.98	0.0096	0.98	0.0071	0.98	0.0095	0.99	0.0067
	Agri_other	0.98	0.0145	0.99	0.0126	0.98	0.0141	0.99	0.0123
	Construction	0.98	0.0149	0.99	0.0124	0.98	0.0149	0.99	0.0124
	Electricity	1.00	0.0013	1.00	0.0010	1.00	0.0003	1.00	0.0003
	Manufacturing	0.98	0.0146	0.99	0.0124	0.98	0.0146	0.99	0.0125
	Mining	0.98	0.0199	0.99	0.0179	0.98	0.0199	0.99	0.0179
	Petroleum	0.98	0.0151	0.99	0.0129	0.98	0.0151	0.99	0.0129
	Processed Foods	0.98	0.0099	0.99	0.0090	0.98	0.0099	0.99	0.0090
	Services	0.98	0.0141	0.99	0.0120	0.98	0.0141	0.99	0.0120
Energy	Agri_crop	0.98	0.0095	0.99	0.0070	0.98	0.0094	0.99	0.0066
	Agri_other	0.98	0.0149	0.99	0.0127	0.98	0.0144	0.99	0.0123
	Construction	0.98	0.0139	0.99	0.0120	0.98	0.0139	0.99	0.0120
	Electricity	0.96	0.0892	0.96	0.0505	0.96	0.0800	0.97	0.0454
	Manufacturing	0.98	0.0147	0.99	0.0124	0.98	0.0148	0.99	0.0125
	Mining	0.98	0.0224	0.99	0.0188	0.98	0.0224	0.99	0.0188
	Petroleum	0.98	0.0152	0.99	0.0128	0.98	0.0152	0.99	0.0128
	Processed Foods	0.98	0.0098	0.99	0.0089	0.98	0.0098	0.99	0.0089
	Services	0.98	0.0138	0.99	0.0118	0.98	0.0139	0.99	0.0118

Several key observations can be drawn from Table 2 with regard to the economic impacts of climate change channels on Zambia's economic sectors.

Agriculture

The agriculture channel has no significant impact on most sectors save for the agric_crop and processed foods sectors which show change under both UCE and L1S scenarios. However, like in most cases, UCE outcomes are more uncertain. This uncertainty in these sectors under UCE policy is because of inter-linkages between them, with the processed foods sector drawing its inputs from the agric_crop sector, and because much of the output of the agric_crop sector is rain-fed, so that uncertainty in precipitation directly affects outputs of the agric_crop sector. However, even though there is some change in both value addition and production in these two sectors under the channel, this change is not significant.

Roads

Under this channel, the centrality of infrastructure in the economy is emphasised. The impacts of climate change on GDP (see Figure 7 above) through this channel introduces the most uncertainty in the economy. This is because the roads channel has strong linkages to all sectors save for electricity. The two most negatively affected sectors are mining and petroleum, with the electricity sector gaining. Impacts on the mining sector result in other economic shocks, such as uncertainty in the foreign exchange market, since the mining sector is the largest foreign exchange earner. Similarly, the petroleum sector provides key inputs to all productive sectors of the economy. Therefore, shock to the petroleum sector has ripple effects on the economy.

Furthermore, under this channel, the agriculture sector contribution to GDP is the more uncertain, as shown in Figure 8. This is because of the uncertainty in production of sectors that have both forward and backward linkages with the agriculture sector, among other reasons. For instance, a wetter climate may benefit agriculture while at the same time cause damage to road infrastructure. On the other hand, a drier climate could be disastrous for crop production but may at the same time be positive for road infrastructure.

The analysis of the roads channel shows the importance of having a climate-adaptive approach towards roads and, indeed, general infrastructure development. Road infrastructure plays a key role in promoting economic productivity. For example, sectors such as mining and agriculture use roads to access raw materials for their production as well as links to markets. In addition, damaged road infrastructure will require repair or rehabilitation, which is an opportunity cost as it diverts funds from other development ventures, such as building new road networks or extending existing ones. The importance of having an adaptive approach to road and infrastructure cannot be over-emphasized, as Chinowsky et al. (2015) observe that lack of an adaptive approach could cost Malawi, Mozambique and Zambia about USD 596 million in road maintenance and repairs, as a result of damages directly caused by changes in precipitation and temperature.

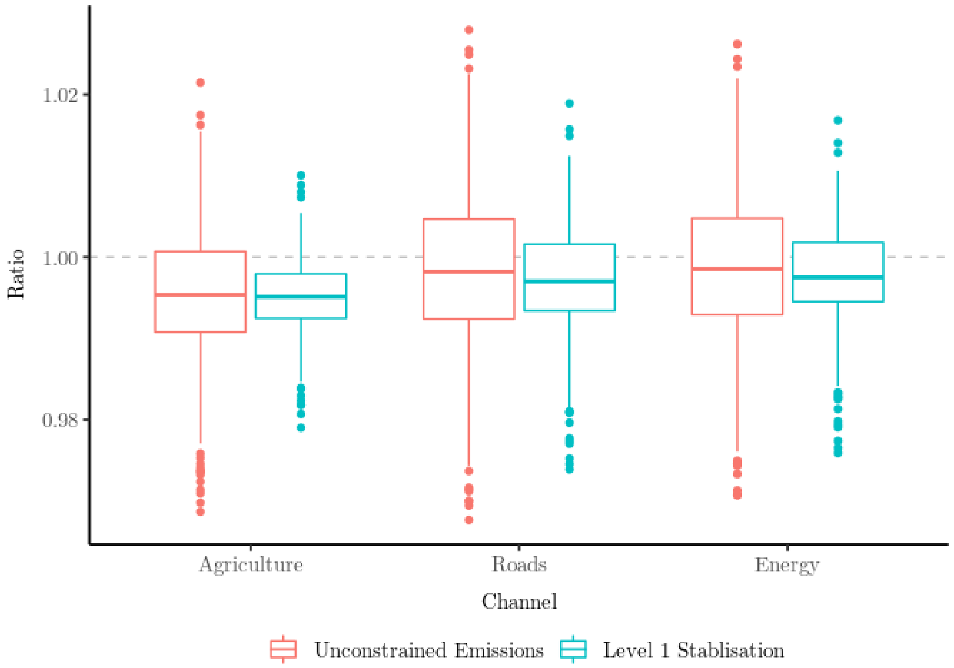

Figure 8: Changes in agriculture sector contribution to GDP relative to baseline due to climate change by channel (for 2045–2050 period)

Energy

Under both policy scenarios, the energy channel exerts more pressure on electricity than on other sectors. Both scenarios show significant uncertainty for the electricity sector. Compared to other sectors, value addition and production reduces more in the electricity sector, as shown in Figure 4 above. This is not surprising, given that Zambia's electricity generation is hydro-power, which is vulnerable to climate change and variability. This result is consistent with the findings by Fant, Gebretsadik and Strzepek (2013), whose study projects a reduction in hydro-power production in Zambia due partly to the reduction in run-off and the increase in irrigation activities upstream of the major hydro-power generation plants.

Besides the impacts on the electricity sector, the energy channel generally has a negative effect on all sectors under both policy options but with relatively higher uncertainty on the mining, agriculture, petroleum and manufacturing sectors under the UCE policy scenario. As mentioned in the preceding sub-sections, uncertainty makes it more difficult and costly to develop a robust policy response to climate change impacts. Considering Zambia's energy mix and the planned hydro-power projects by the government and the electricity utility, ZESCO,[11] electricity supply could be greatly impacted if no deliberate efforts are made to diversify from a hydro-dominated system. Furthermore, if no diversification efforts are made, and with a shortage of electricity supply from the regional market, Zambia would be forced to develop quick but expensive electricity supply options such as oil, as happened in East Africa (Karekezi et al., 2009). Generation of electricity from diesel and heavy fuel oils would not only increase emissions but also put significant pressure on the country's reserves, as the import bill for oil would increase. The importance of diversifying from hydro-power in the light of climate change is also emphasised by Spalding-Fecher et al. (2017), who conclude that Zambia's hydro-power system is highly vulnerable to climate change, such that even the expansion of the Kariba generating capacity or installation of the planned Batoka Gorge plant may not reach expected increases in production.

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[11] Hydro-power technology is a cost-effective option (Tembo, 2012; 2018).

4.5 Summary discussion

The sub-section presents a summarised discussion of key findings of the analysis of potential impacts of different climate change channels (i.e. agriculture, roads and energy) in a synthesised way: both from literature review and model output analyses. From the model projections, the overall growth of the economy is expected to be affected particularly by the roads channel, which causes a reduction in value-added activities mainly in the agriculture, mining, processed foods and manufacturing sectors. Reduction in the mining sector's production, particularly, leads to negative impact on other sectors and also on the exchange rate, as mining accounts for close to 70% of Zambia's foreign exchange earnings.

As stated above, the roads channel introduces significant uncertainty in the economy, arising from envisaged changes in climate. Thus, road infrastructure development plans need to be adapted to different climatic conditions. For example, when road infrastructure is adversely affected by climate variability (flooding and high temperatures), market connectivity in the agriculture sector and transportation of metals are affected. The analysis has also shown that, with the projected rise in temperature and changes in precipitation, there are varied levels of uncertainty in the overall economy.

To elaborate, under the energy channel, the electricity sector (that is local electricity production) will be most affected. Decrease in local electricity hydro-power production means reliance on foreign supply of electricity, which implies increased energy supply insecurity. Further, increased uncertainty in local electricity production means potential erratic supply, to mitigate which would require increased imports of electricity to meet the deficit. Notwithstanding, Zambia is aims to be a net exporter of electricity by 2025. Whether this vision can be actualized or not calls for further analysis of the potential risks facing the hydro-power generation vis-à-vis electricity supply.

5 CONCLUDING REMARKS

The paper presented the findings of an analysis of the economy-wide implications of climate change in Zambia. Overall, climate change is expected to lead to a decrease in real GDP. However, the impacts of the UCE policy scenario would be worse than those of the L1S scenario. At sectoral level, it was found that the largest impact of climate change would be on the electricity and agriculture sectors. The reduction in electricity production implies increased energy supply insecurity and failure to become a net electricity exporter in the region. Reduction in agricultural crop yields has far-reaching impacts, such as increased food insecurity, reduced welfare and employment. Moreover, it means that the production of biofuels feedstock from the agriculture sector could be compromised. Details on the agriculture sector analysis can be found in Ngoma et al. (2020).

This paper also highlighted the need to develop adaptation policies to avert the effects of climate change on the overall economy, particularly for road infrastructure. The analysis showed that the roads channel introduces significant uncertainty to the economy as a result of climate change, which would have ripple effects across the whole economy. The uncertainty in the roads channel particularly affects the agriculture and mining sectors. This means that there should be corresponding policies and strategies that could avert these impacts. Further, there should be deliberate policy focus on maintaining and developing road infrastructure that is resilient to the effects of climate change.

Finally, there is need to use an updated social accounting matrix in the CGE model. The 2007 SAM is dated and the structure of Zambia's economy has significantly changed. For instance, almost all – over 98% – of Zambia's electricity supply in 2007 was from hydro-power; by 2016, the proportion was down to 85%. Similarly, the role of mining in the economy continues to change, as evidenced by the increase in production numbers and fluctuation in real global copper prices. Therefore, to make better policy recommendations, usage of up to date data cannot be overemphasised. This work showed the feasibility and value of using analytic tools to aid strategic decision-making. However, to repeat, up-to-date data is required to enhance and enrich policy recommendations.

APPENDIX A: CLASSIFICATION OF ACTIVITIES AND COMMODITIES

The table below shows how activities and commodities were classified to simplify both sector analysis (sub-section 4.4) and trade analysis (shown in different figures).

Table 3: Classification of activities and commodities by sector

Activity/commodity	Sector (sector analysis)	Commodity trade analysis
Horticulture	Agri_crop	Agricultural
Cotton	Agri_crop	Agricultural
Maize	Agri_crop	Agricultural
Root crops	Agri_crop	Not tradeable
Other cereals	Agri_crop	Agricultural
Tobacco	Agri_crop	Agricultural
Sugarcane	Agri_crop	Not tradeable
Pulse and oilseed	Agri_crop	Not tradeable
Other crops	Agri_crop	Not tradeable
Forestry	Agri_other	Not tradeable
Fisheries	Agri_other	Not tradeable
Livestock	Agri_other	Agricultural
Electricity	Electricity	Electricity
Food	Processed foods	Processed foods
Mining	Mining	Mining
Coal	Mining	Not tradeable
Services	Services	Services
Trade and hotels	Services	Services
Transport	Services	Services
Finance	Services	Not tradeable
Business and real estate	Services	Not tradeable
Other services	Services	Not tradeable
Chemicals	Manufacturing	Manufacturing
Machinery	Manufacturing	Manufacturing
Non-Metals	Manufacturing	Manufacturing
Metal	Manufacturing	Manufacturing
Other Manufacturing	Manufacturing	Manufacturing
Construction	Construction	Not tradeable
Petroleum	Petroleum	Oil

Textiles	Manufacturing	Manufacturing
Wood	Manufacturing	Manufacturing

APPENDIX B: IMPACTS OF CLIMATE CHANGE ON ZAMBIA'S EXCHANGE RATE AND INFLATION

The impacts of climate change on exchange rate are given in Figure 9. Relative to L1S, UCE shows improvements in the exchange rate when all the three channels are considered. This implies that, under UCE, the Kwacha is expected to appreciate against major trading currencies compared to the L1S policy scenario. However, the behaviour of the exchange rate under the UCE policy scenario is more uncertain than L1S. For planning purposes, this means that it would be more challenging for the government to implement its monetary policy under this policy scenario.

The appreciation in the exchange rate under the UCE policy scenario can partly be explained by the favourable exports (relative to imports) compared to the L1S. Figure 10 shows the overall export to import ratio, by value. It can be seen that under the UCE, the ratio is closer to 1 than under the L1S. This means that, by value, the trade balance under the UCE is expected to be narrower than under the L1S. In both policy scenarios, as expected, most uncertainty in trade balance is under the energy channel, because of electricity imports.

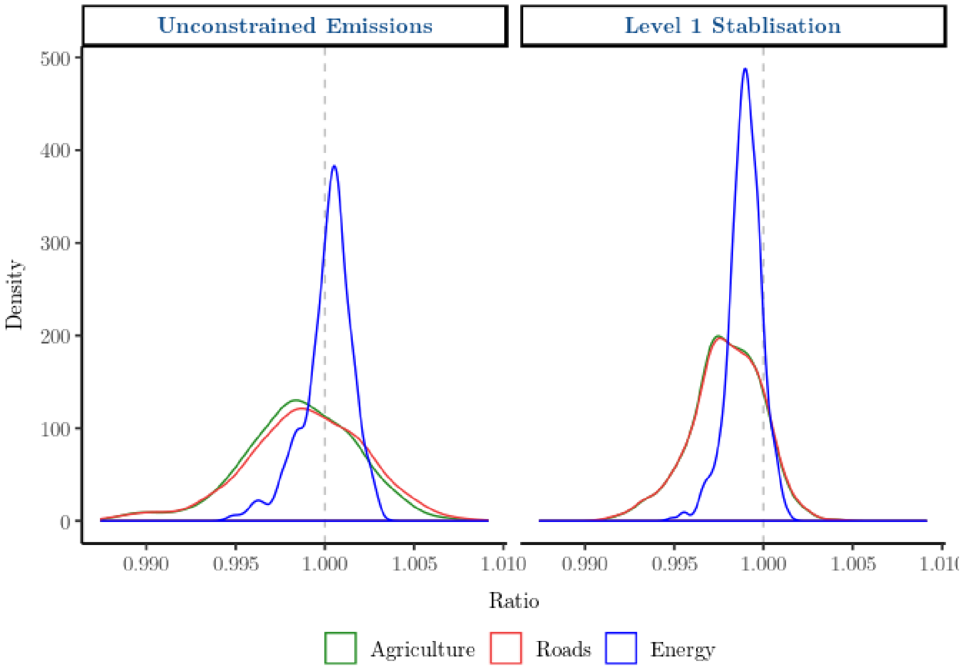

Figure 9: Changes in exchange rate relative to the baseline due to climate change, by channel (2045-2050)

The implications of climate change on inflation (consumer price index, CPI) are given in Figure 11. It can be seen there that the bulk of the outcomes result in an increase in the CPI under both policy scenarios. L1S shows a smaller band (spread) than UCE, meaning that there the rise in inflation is more contained. However, relative to L1S, a considerable share of outcomes under UCE show that CPI might reduce.

The uncertainty of the outcomes of CPI is more pronounced under the energy channel and least pronounced under the agriculture channel, in both policy scenarios. The rise in inflation can partly be attributed to the reduction in the productivity of the agriculture and processed food sectors (see sub-section 4.4). This reduction results in a supply shock and the difference is made up for by imports. Thus, this highlights the urgent need for climate-resilient agricultural practises in order to reduce the vulnerability of this sector to climate change. For a detailed analysis of how climate change would impact the agriculture sector, see Ngoma et al. (2020). Alongside the inflation impact from the agriculture sector, rising energy costs (for both electricity and petroleum) also boost inflation.

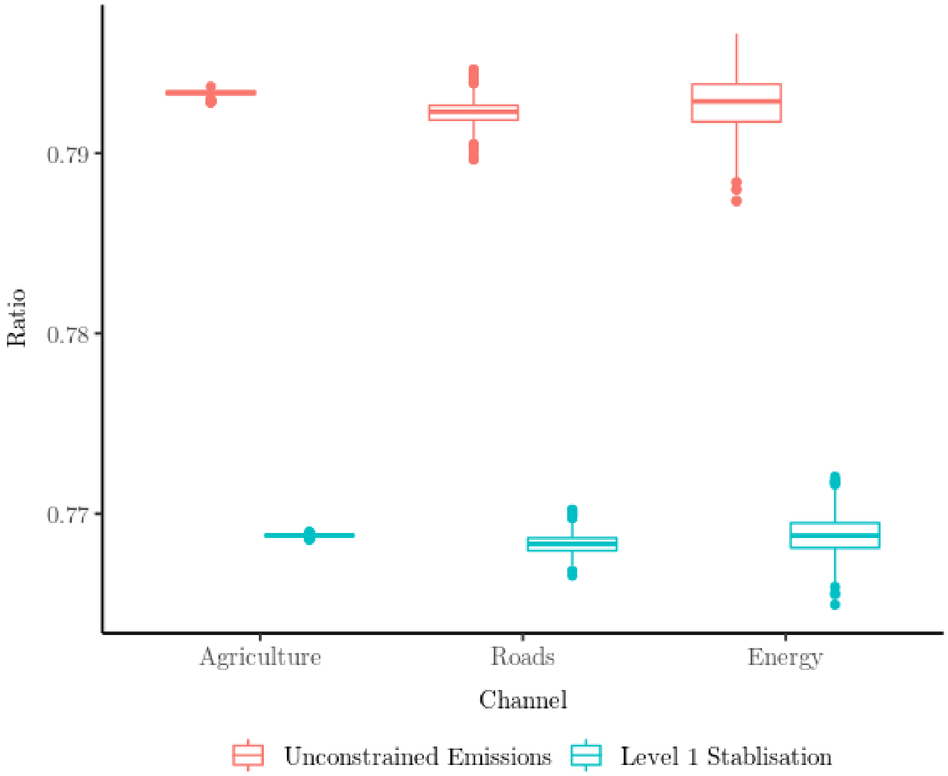

Figure 10: Changes in export-import ratio due to climate change, by policy scenario (2045–2050)

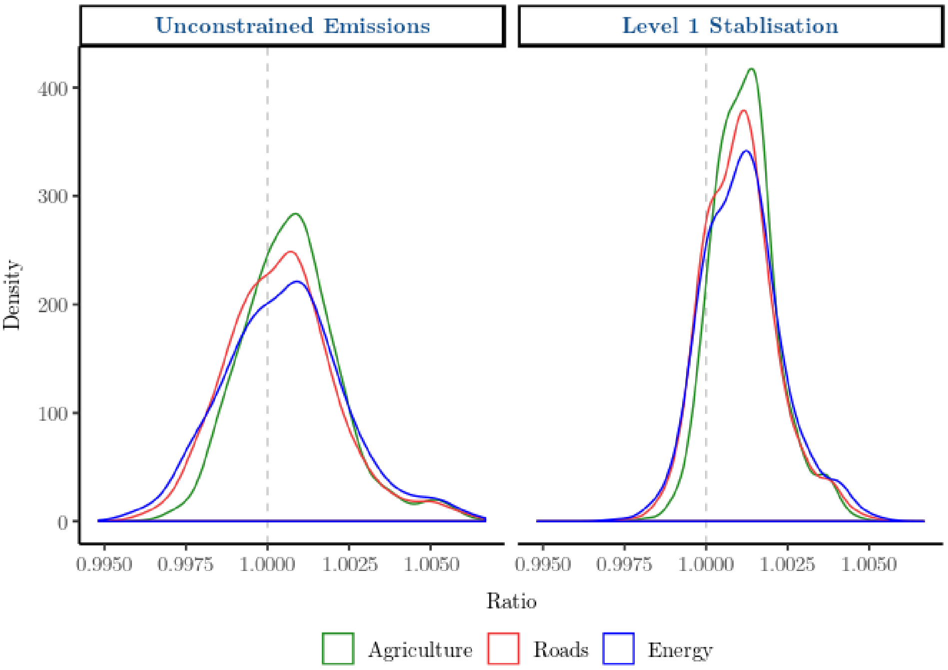

Figure 11: Changes in inflation relative to baseline due to climate change, by channel (2045-2050)

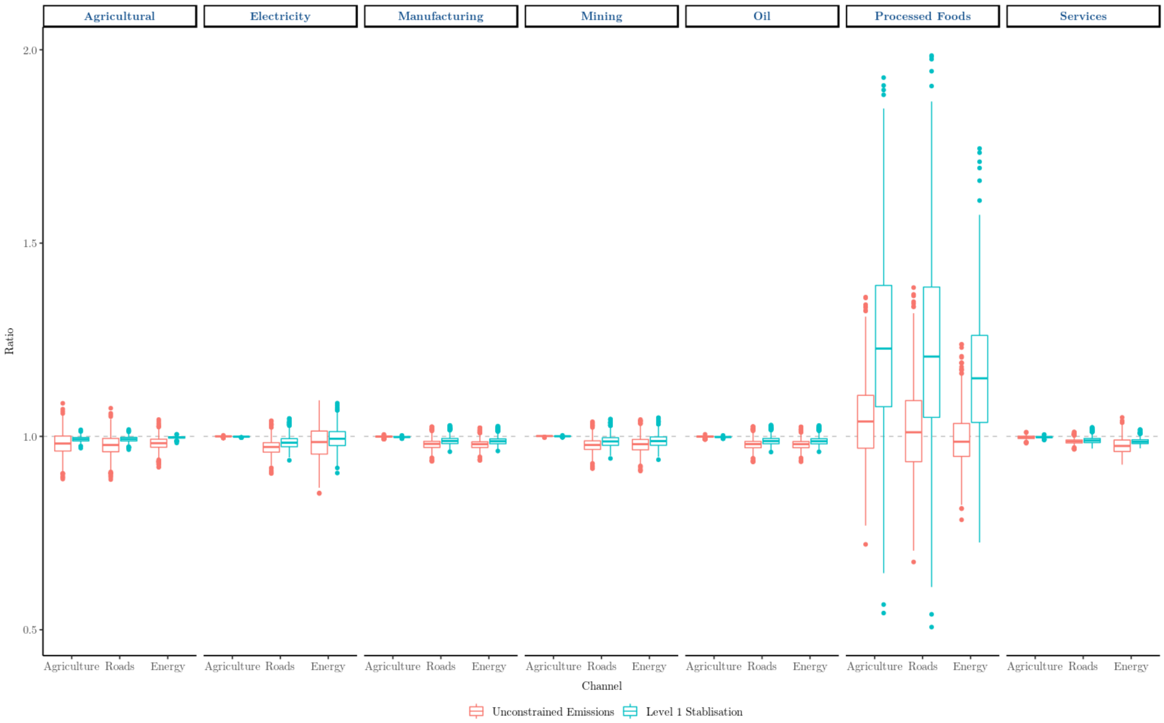

Figure 12: Commodity trade relative to Baseline due to climate change, by channel (2045–2050)

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