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Impacts of climate change on agriculture and household welfare in Zambia

An economy-wide analysis

Hambulo Ngoma, Patrick Lupiya, Mulako Kabisa, and Faaiqa Hartley

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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.

Towards Inclusive Economic Development in Southern Africa

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ABSTRACT

While there is consensus that rainfed agriculture is the primary impact channel for agrarian economies like Zambia, it is uncertain what the future climate will be like, how it will affect different economic sectors, and by what magnitudes. Despite some evidence on the impacts of climate change on agriculture in Zambia, gaps remain in understanding the likely impacts of climate change on agriculture at subnational/regional level and for different crops. This paper contributes towards filling these gaps and assesses the potential impacts of climate change on agricultural production and welfare at national and subnational/regional levels. We use data from global circulation models (GCM) that are based on 398 climate scenarios for the level one stabilization (L1S) – where there is global climate mitigation action, and 421 scenarios for the unconstrained emissions (UCE) – where there are no global efforts to limit carbon dioxide concentrations in the atmosphere. Unlike past studies, this paper combines biophysical and economy wide modelling, covering the entire gamut from climate science to economic outcomes and attempts to address the uncertainty with climate outcomes by utilizing 819 potential climates.

Overall, rainfall is projected to reduce by 0.87 percentage points at national level, and by between 3 and 4 percentage points in the worst affected Southern and Western regions of Zambia by end of the period covered by the study in 2050. Over the same period, temperature is projected to increase by 1.82°C. The projected changes in temperature and rainfall will be more prominent under UCE compared to L1S climate futures. The Western and Southern regions of the country will be the worst affected. Climate change is projected to reduce maize yield and production much more than for any other crop considered in the analysis, and these reductions will be highest in the Southern and Western regions. In terms of the economic impacts, climate change is projected to reduce GDP, especially in the fourth decade covered by the study between 2041 and 2050, and these negative impacts will be progressive as will be the uncertainty of these impacts.

Climate change will likely reduce net agricultural exports at national level, the share of agriculture in GDP, and the cumulative impacts on agriculture share in GDP will be more significant in the fourth decade between 2041 and 2050. These impacts will in turn reduce household expenditure. These results speak to the future of smallholder agriculture and call for a need to: (i) transform the agricultural sector by investing in climate-smart technologies such as irrigation, and heat and drought tolerant crop varieties; (ii) diversify production away from maize and identify suitable alternative farm enterprises for the most vulnerable regions in the Southern and Western parts of Zambia; (iii) build on existing evidence showing that mitigation lessens the negative impacts of climate change to garner political will for climate action; (iv) and lastly, lobby for more budgetary allocations to support subnational and local level mitigation and adaptation actions.

1 INTRODUCTION

Now more than ever, there is a consensus that the world's climate system has changed as a result of human action. Effects are vividly clear in natural ecosystems and in human systems and wellbeing, with the poor and those already grappling with food insecurity, expected to be hardest hit (De Pinto et al., 2019; Hoegh-Guldberg et al., 2018). In its 2018 special report, the Intergovernmental Panel on Climate Change (IPCC) warns that an increase in temperature of 1.5˚C above pre-industrial levels will result in significant risks to food security, livelihoods, and economic development. A warmer climate is expected to adversely affect rural populations that rely on agricultural production for their livelihoods (IPCC, 2018). This is because agricultural systems are vulnerable to climate variability and change, and a higher frequency and intensity of extreme climate events is likely to disrupt food systems, which in turn negatively affects food access and human nutrition (Meybeck et al., 2018). Despite overwhelming evidence of the impacts of climate change, it is widely argued that more must be done to mitigate and adapt to climate change. Agricultural and natural resource sectors, which are responsible for 23 percent of the greenhouse gas (GHG) emissions globally, and 30 percent for sub-Saharan African countries, have continued with "business as usual" approaches in responding to the climate crisis (Smith et al., 2014; Braimoh et al., 2016).[1]

Notwithstanding, climate change is marked by uncertainty. It is uncertain what the future climate will be like, and how and by what magnitude climate change will affect different economic sectors (Fant et al., 2015). Rainfed agriculture is the primary impact channel for agrarian economies like Zambia – the focus of the present study; and agriculture is an important economic sector in the whole of Sub-Saharan Africa (SSA). It gives livelihoods to over 50 percent of the labour force in SSA, and employs 22.3 percent of the labour force in Zambia, providing livelihoods for over 50 percent of the population (ZamStats, 2019; OECD/FAO, 2016; GRZa, 2016). However, agriculture's dependence on rainfall exposes the sector to climate shocks and makes rural households vulnerable to climate change. The effects of climate change on agriculture are both direct and indirect. It directly affects agricultural production and productivity, assets and household incomes, and indirectly affects factor prices and off-farm employment opportunities (Olsson et al., 2014; Porter et al., 2014). Further, climate change can make irrelevant and useless the climate information that has been collected for decades (Arndt et al., 2014).

Given the inability to adequately address the uncertainty associated with climate change, existing studies have mostly focused on changes in biophysical factors such as average temperatures and rainfall – with little attention given to the broader range of potential economic impacts of climate change on agricultural production, food prices and household welfare (De Pinto et al., 2019). This could in part be due to the absence of economy-wide data and analytical frameworks that are required to assess such impacts (Arndt et al., 2011). Given that the agricultural sector in Zambia employs 18 percent of the people in the informal sector and 4.3 percent of those in the formal sector, and contributes an average of 6 percent to gross domestic product (GDP), it is important to assess and quantify how climate change will likely impact the sector in order to make a case for climate action, and also to assess the cost of inaction (ZamStats, 2019; Mulenga et al., 2019a; Sesmero et al., 2018).

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1 Results are for 33 countries in the region.

Understanding how and where the impacts of climate change will be most felt is critical for adaptation planning at regional, national and subnational levels. In Zambia, climate change is projected to increase poverty, increase incidents of crop failure, change the length of the growing season, and lead to a 13 percent reduction in water availability by 2050 (Ngoma et al., 2019; Hamududu and Ngoma, 2019; Verhage et al., 2018; Mulenga et al., 2017). Some studies suggest that the impacts in Zambia will differ by agro-ecological region, increase the demand for crop diversification, and reduce national GDP by 4 percent (Mulungu et al., 2019; Braimoh et al., 2016).

Despite the established evidence of the impacts of climate change on agriculture in Zambia, gaps remain in understanding the likely impacts at subnational level and for different crops. Such an understanding is important in order to inform the agricultural production and development policies needed to mitigate and adapt to climate change and variability. This paper contributes towards filling these gaps and assesses the potential impacts of climate change on agricultural production and welfare at national and subnational levels, and for various crops. Existing literature is complemented in two ways. First, while this study is similar to other studies that combine both biophysical and economic models to evaluate the impacts of climate impacts on agriculture at both national and regional level (e.g., Thurlow et al., 2012; Mulungu et al., 2019), it adds to these studies by including more crops than previous studies, and accounts for the uncertainty of climate outcomes by using 819 potential climate scenarios.[2] Second, unlike other studies done at national and regional level that mostly focus on biophysical outcomes, energy, and infrastructure separately (e.g. Chinowsky et al., 2015; Fant et al., 2013; Fant et al., 2015; Schlosser and Strzepek, 2015), this study combines biophysical assessments with an economy-wide modelling framework that allows for a more nuanced analysis at national, subnational or regional levels of the socio-economic impacts of climate change on poverty, agricultural trade, and household welfare. Specifically, the following questions are addressed:

- What are the potential impacts of climate change on crop yields in Zambia and what do they mean for existing national agriculture policy?
- What are the potential impacts of climate change on agriculture production at national and subnational levels?
- What are the implications of climate change for agricultural trade and economic development?
- What are the impacts of climate change on household welfare, poverty and food security at national and subnational levels?
- What do the impacts of climate change on agriculture, household welfare, food security imply for adaptation in Zambia?

The rest of the paper is organized as follows. Section 2 gives a brief review of the impacts of climate change on the agricultural sector in Zambia, and Section 3 describes the methods of the present research and provides brief details on the biophysical, crop and economic models used. The results answering the main research questions are then presented in Section 4, which is followed by a discussion of the main results in Section 5. The paper ends with a conclusion in Section 6 that draws implications for policy in Zambia.

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[2] Additional crops include root crops (cassava), other cereals (millet, sorghum, rice etc.), tobacco and sugar.

2 CLIMATE CHANGE AND AGRICULTURE – A BRIEF REVIEW

This section reviews literature on the known impacts of climate change on agricultural production in the southern African region, especially in Zambia. Specifically, it discusses Zambia's agricultural sector and what is known so far on how exposure to climatic shocks affects crop yields, agricultural production, agricultural trade, and household food security, nutrition and welfare.

The impacts of climate change are already being experienced in SSA. Along with increased frequency of extreme climate events such as droughts and floods, climate change is projected to further reduce agricultural yields in the region by the 2030s and 2040s. These outcomes are most probable under the "business as usual" or unconstrained emissions (UCE) scenarios, where there is little to no effort towards constraining GHG emissions (Arndt et al., 2014). It is expected that the impacts of climate change will vary in scale and by region. Some regions will experience agricultural productivity gains, whereas others will experience losses. This has already been seen from previous El Niño events in eastern and southern Africa (Al Mamun et al., 2018).[3] De Pinto et al. (2019) posit that agricultural productivity gains in some areas are likely to be outweighed by losses in other areas so that, on average, most regions will experience net losses. For example, the Zambezi basin countries (Malawi, Mozambique and Zimbabwe), and in particular Zambia, are projected to be drier in the southern, and wetter in the northern parts. For the Zambezi basin region, climate change is projected to decrease crop yields, reduce water availability, and increase demand for irrigation (Fant et al., 2013; Verhage et al., 2018; Hamududu and Ngoma 2019). The extent to which households will be affected by climate change is mediated by socio-economic status, demographics, physical ability and cultural factors that also influence resilience and vulnerability (IPCC, 2014).[4]

2.1 Overview of Zambia's agricultural sector

The agricultural sector in Zambia has contributed an annual average of over 6 percent to national GDP during the past decade (World Bank, 2019). As stated above, the sector provides 22.3 percent of employment opportunities in the country, with 4.3 percent in the formal sector and 18 percent in the informal sector (ZamStats, 2019). Smallholder farmers dominate the sector and production is largely maize-centric and rain-fed (Libanda et al., 2019). This production system has left the country, particularly rural smallholders, vulnerable to climate variability and change (mostly droughts) as has been seen in the last few agricultural seasons. Climate change and variability have led to crop failure, livelihood losses, increased incidents of food insecurity, and reduced contribution of agriculture to GDP (Alfani et al., 2019; Chisanga et al., 2017; Chisanga et al., 2018; Mulenga et al., 2019b). Evidence suggests that investing in rural smallholder farms can accelerate the structural transformation that ultimately supports rural non-farm income (Snyder et al., 2019). Similarly, Cullis et al. (2015) suggest that the negative impacts of climate change on agriculture reverberate directly and indirectly in the national economy when agriculture makes significant contributions to livelihoods. The general impacts

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3 For example: Malawi was adversely affected by the drought; Zambia recorded high yields in the northern parts of the country and crop failure in the southern parts but the north-south divide impacts were not clear cut and highly variable; and the impact on real farm income in Tanzania was insignificant.

4 Resilience is defined by the IPCC (2014) as "The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation".

of climate change on the sector are expected to differ by crop and agro-ecological region due to changes in temperature and precipitation. Thus, agricultural systems that are resilient to climate variability and change can contribute to overall economic development.

2.2 Climate change, agricultural production and crop yields

Climate change will impact agricultural productivity through the increased frequency and more extreme nature of climatic events like droughts and floods that directly affect agricultural production (Jain, 2007; Thurlow et al., 2012). Because climate change is uncertain, it is difficult for farmers to plan their agricultural production activities, especially in rainfed farming systems (De Pinto et al., 2019). Climate change and variability lead to higher uncertainty in predicting weather events such as floods and dry spells, and shifts in the onset and offset of rains. The impacts of climate change on crop yields are already being felt, with declines in lower-altitude regions of staple crops such as maize and wheat, while higher altitude areas have seen increased yields for sugar beets, maize and wheat (IPCC, 2014; IPCC, 2019). Climate projections show that, overall, Zambia will be hotter and drier. Climate change is projected to affect the southern parts of Zambia more than the northern, and, on average, rainfall is expected to be more variable and rainy seasons are likely to shift (Ngoma et al., 2017; Hamududu and Ngoma, 2019; Mulenga et al., 2017). Since over 90 percent of smallholder production is rainfed and the market conditions are poor, Zambian agriculture is vulnerable to climate shocks (GRZ, 2016a; GRZ, 2016b). Further, Zambia has witnessed crop failure in the western and southern parts, electricity rationing of up to 15 hours per day due to rainfall variability, and high volatility in maize and maize meal prices due to supply shortfalls and limited irrigation (Mulenga et al., 2019b; Chisanga et al., 2018).

2.3 Climate change and agricultural trade and development

Climate change affects agricultural trade and development through food prices. Reduced food supplies lead to higher food prices, which invariably affect the most vulnerable and increase the risk of hunger and food insecurity (IPCC, 2019). The expected reductions in crop yields and agricultural production in the region suggest that agricultural imports will be needed in order to achieve sufficient supplies of staples such as maize and other cereals. However, it can be costly for the state to rely on imports to meet local food requirements. It is also expected that frequent climatic events may lead to losses in current and future agricultural incomes and wages (Alfani et al., 2019). This would leave the southern African region vulnerable because climate change will impact the amount of food produced, limit access to this food, limit trade opportunities, and lead to higher import costs. Combined, these factors will disadvantage SSA countries because of trade imbalances and poorly developed domestic and regional markets (Ludi et al., 2007).

Although not directly addressed in this paper, infrastructure is another potential impact channel of climate on trade and welfare. Investments in infrastructure such as rural roads are key drivers of poverty reduction and economic and agricultural development in agrarian economies (Arndt et al., 2012; Chinowsky et al., 2015). Increased incidences of extreme climate events damage infrastructure, leading to severed market linkages and access, which in turn limit market participation. Inadequate infrastructure to facilitate agricultural trade, as is common in Zambia, will lead to increased food price volatility, and limit income-generating opportunities through trade in the coming decades (Hertel et al., 2018; Al Mamun et al., 2018). This supply pressure will negatively impact agricultural trade and development as poor harvests are projected to worsen progressively. The knee-jerk government reaction to this supply pressure through trade bans, as seen in the recent past, will limit formal exports, increase price volatility, and reduce foreign exchange earnings (Chisanga and Chapoto, 2016; Mulenga et al., 2019a). In fact, Al Mamun et al., (2018) find that the grain price volatility as a result of trade bans increased poverty more than El Niño events in Zambia.

2.4 Climate change, household welfare, and food and nutrition security

The advent of more frequent extreme climate events is radically changing the way in which food security can be achieved, and hunger eliminated (von Grebmer et al., 2019). Climate-related risks and disasters can lead to social instability, diminish livelihood options and economic opportunities, and increase disease prevalence. These factors are important elements that directly impact national food security and nutrition (Fanzo et al., 2018). Globally, about 100 million people are expected to fall back into poverty by 2030 as a direct result of climate change (Halllegate et al., 2016). The majority of these in SSA are expected to be the marginalized who live in the driest and the wettest parts (Azzari and Signorelli, 2020; Olsson et al., 2014;).[5] It is projected that food security in Africa will likely be disrupted due to the frequency and magnitude of extreme climate events, and that the nutritional quality of crops will be lowered (IPCC, 2019). Specifically, disruption of food systems due to extreme events will exacerbate the malnutrition burden through limiting access to diverse and healthy diets. This will be more profound in communities that depend on agriculture and natural resources for their livelihoods, such as Zambia (Meybeck et al., 2018). In addition, these impacts will interact with non-climate stressors and other underlying vulnerabilities such as inequality and poverty that influence vulnerability and resilience to climate shocks (Hoegh-Guldberg et al., 2018; Olsson et al., 2014).[6]

The impact of climate change on food security and nutrition in Zambia will be high because of high poverty levels and low diversification in food production (Verhage et al., 2019; Alfani et al., 2019). Currently, about 63 percent of human energy requirements in Zambia come from cereals and yet cereals like maize – the staple food – are vulnerable to climate change. Thus, disruptions in cereal production and supply will impact food access (Mwanamwenge and Harris, 2017). Heavy reliance on maize compromises the country's efforts to build climate resilience and ensure sustainable food and nutrition security, as exemplified by Zambia's low ranking on the global hunger scale (Mwanamwenge and Cook, 2019; von Grebmer et al., 2019).

3 DATA AND METHODS

The current study used data from global circulation models (GCMs), based on 6800 future climate projections but reduced to 398 for the level one stabilization (L1S) and 421 for the UCE scenario, using the Gaussian quadrature approach (Arndt et al., 2014). The UCE scenario assumes no successful global efforts to mitigate GHG emissions, while L1S assumes successful global efforts to mitigate and adapt to climate change (Webster et al., 2012 and Fant et al., 2015).

As explained in Fant et al. (2013), the biophysical models are used to simulate water demand, estimate the impacts on crop yields, or the changes in crop yields and runoff. The outputs from the GCMs are the inputs for the different biophysical models, which eventually compute the outputs that are used in the economy-wide modeling. This study focused on five crops or groups of crops, namely maize,

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5 Inequalities that may be based on gender, race, socio-economic status, geographic location etc. (Olsson et al., 2014).

6 There will be differences in how the poor are impacted by climate change because people are poor for various reasons (Olsson et al., 2014).

other cereals (wheat, barley, rice, etc.,), root crops (such as cassava and potatoes), and the non-traditional crops cotton and tobacco. It also focused on the impacts over the average of the last five years of the study, i.e. 2046 and 2050, to avoid the intra-annual variation which will be present in single year results.

The economy-wide economic results are derived from a dynamic computable general equilibrium (CGE) model for Zambia. This is calibrated using a 2007 social accounting matrix (SAM) for Zambia, which had 31 activities and commodities (see Chikuba et al. 2013 for details on the Zambian SAM). The CGE model used assumes that labour can move freely between regions and sectors. Labour is, however, fully employed, with wages adjusting to ensure that on aggregate there will be no differences in employment levels between scenarios. The model further assumes that land has an exogenous growth rate specific to a region and that the agriculture sector competes with other industries for capital. The model includes outputs from the biophysical models as inputs used to estimate the economic impacts of climate change on a range of outcomes. Readers are referred to Arndt et al. (2014) for details on the CGE framework used in this study.

The models include sub-regions and are run over time to 2050 and provide a nuanced picture of the biophysical and economic impacts of climate change in Zambia.

4 RESULTS

This section reports on selected results from the crop biophysical and economy-wide modelling for both the UCE and the L1S scenarios. Recall, UCE assumes that there is no control on global emissions, L1S assumes that there are successful worldwide mitigation efforts to reduce carbon dioxide concentrations in the atmosphere. The biophysical and economy-wide results for both the national and regional/subnational levels for Zambia (central, northern, eastern, southern and western) are reported.[7] The average annual yield deviations are between the baseline scenario where there is no climate change and each of the 421 and 398 different climate scenarios under UCE and L1S respectively, for the period 2046 to 2050. Although climate change can affect outcomes through different channels, the analysis here is restricted to the agriculture channel. The results may therefore differ from those presented by Tembo et al. (forthcoming), which reports compounded results from the agricultural, energy and infrastructure impact channels.

4.1 BIOPHYSICAL RESULTS

This section presents results on projected changes in rainfall and temperature between 2046 and 2050, and on the impacts of climate change on crop yield between baseline and several future potential climate scenarios between 2046 and 2050. Because results under UCE and L1S scenarios are somewhat similar, qualitatively, with the latter expected to be less negative, UCE results are mostly referred to, with occasional noting of the L1S results.

4.1.1 Projected changes in rainfall

Figure 1 shows the percentage change in rainfall over the five years between 2046 and 2050 under UCE and L1S scenarios at the national level. The zero line marks a null deviation between the baseline without climate change and any potential climate change scenario. On average, rainfall is projected to reduce under L1S and increase under UCE because the peak for each scenario is on either side of the

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7 Regions are broadly defined here and each one may include several provinces

zero percent change line. Our results suggest that rainfall for 2046–2050 is likely to increase by 0.67 percentage points under UCE and reduce by 0.87 percentage points under L1S at national level. As would be expected, the unrestricted mitigation scenario (UCE) shows a higher uncertainty of outcomes, given a broad range of extreme value distributions as compared to the level one stabilization.

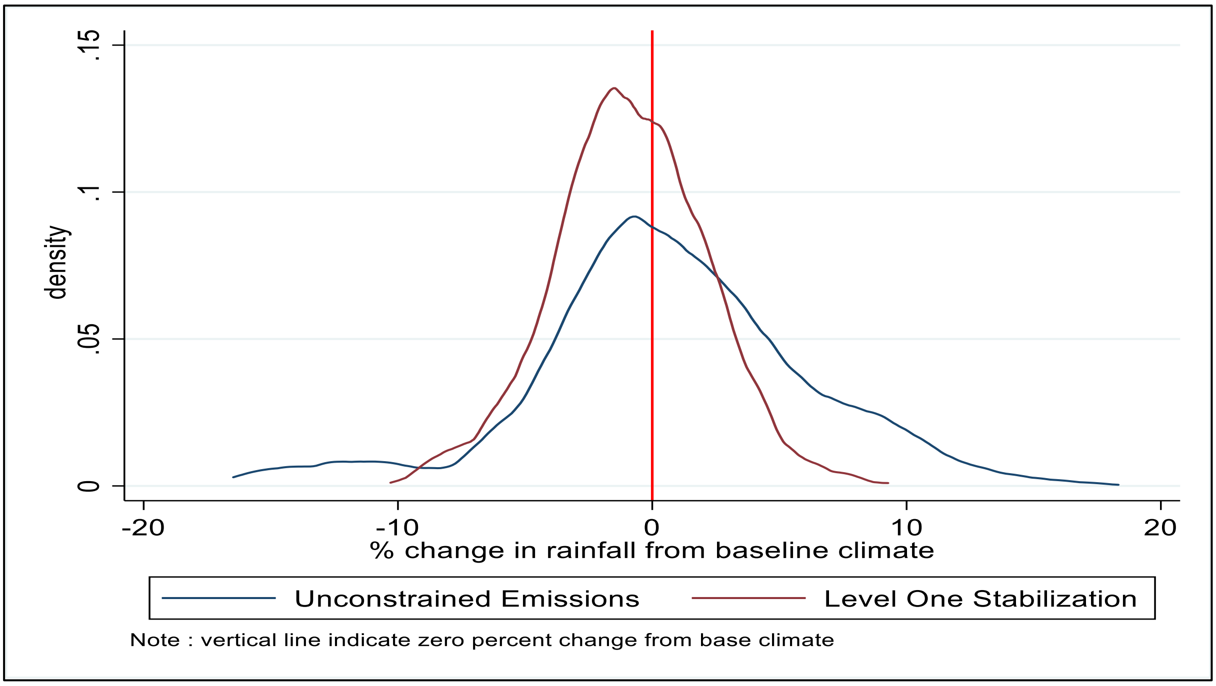

Figure 1: National level percent change in rainfall under unconstrained and level one stabilization, 2046–2050.

The foregoing national level results mask important differences at the regional level, where the southern and western regions have the most substantial reductions in rainfall, averaging between 3 and 4 percentage points (Figures 2 and A13). This suggests that these are the most vulnerable to climate change and will likely experience greater reductions in rainfall over time. By contrast, the northern region is projected to receive nearly 5 percentage points more rainfall by 2050. Tables 1 and A2 give the summary statistics for changes attributable to climate change for all variables of interest, and Figure A2 summarizes the projected median changes in rainfall by region.

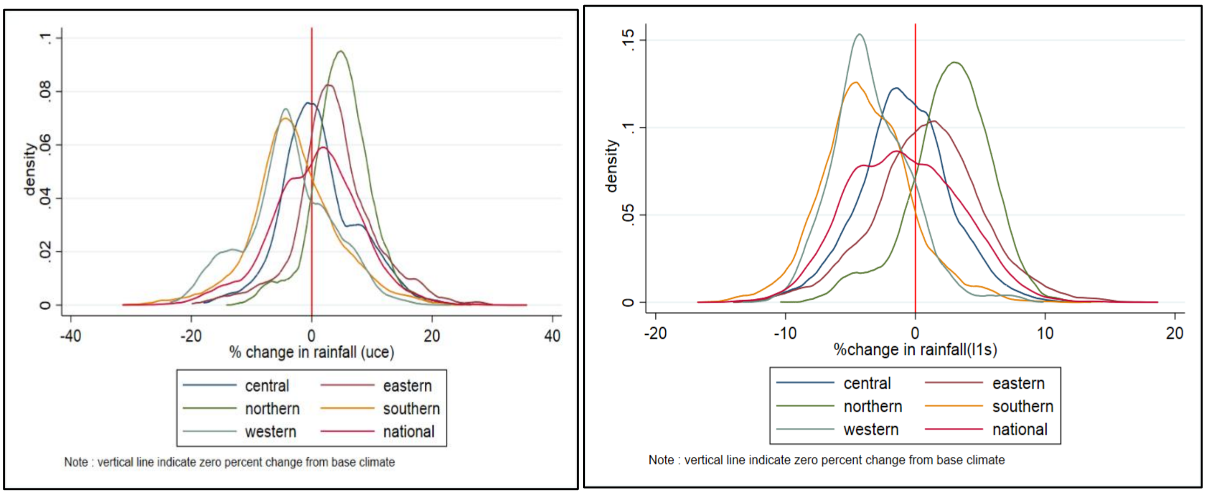

Figure 2: Regional level percent changes in rainfall under unconstrained (left panel) and level one stabilization (right panel), 2046–2050.

4.1.2 Projected changes in temperature

Figure 3 shows the frequency distribution charts for deviations in temperature at the national level for all climate scenarios from 2046 to 2050. The blue and maroon lines are mean temperatures under UCE and L1S scenarios, respectively. At national level, temperature is projected to increase by 1.82°C under the UCE scenario by 2050. While uncertain, temperature is projected to increase much more under UCE than L1S due to the global mitigation assumed under the latter.

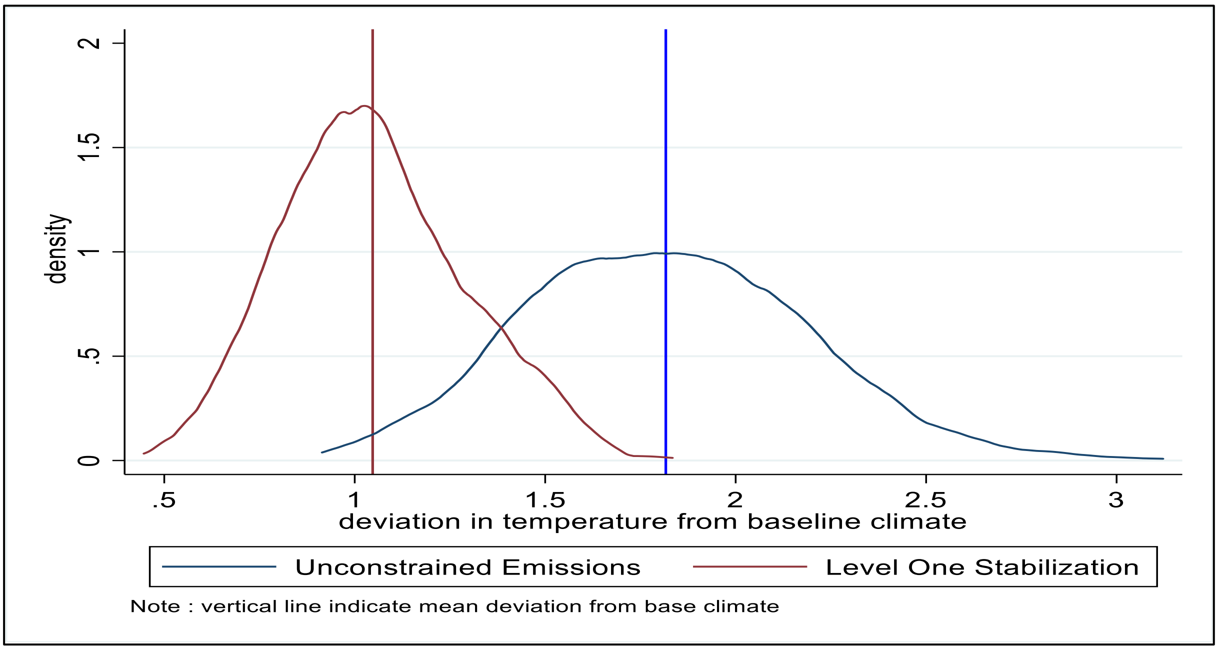

Figure 3: National level temperature deviations from baseline climate under unconstrained emissions and level one stabilization, 2046–2050.

Figure 4 shows the regional-level frequency distribution charts for deviations in temperature across various regions for all climate scenarios from 2046 to 2050. Under the UCE scenario, temperature differences are more pronounced across multiple regions, with the western region showing the most significant deviations – between 0 and 3.8°C. In contrast, the eastern region shows the smallest deviations (Figure 4, top panel). The lower panel in Figure 4 shows that temperature deviations across regions are minimal under L1S when compared to UCE. However, on average, the results project similar increases in temperature for all regions (Table A2 in the appendix).

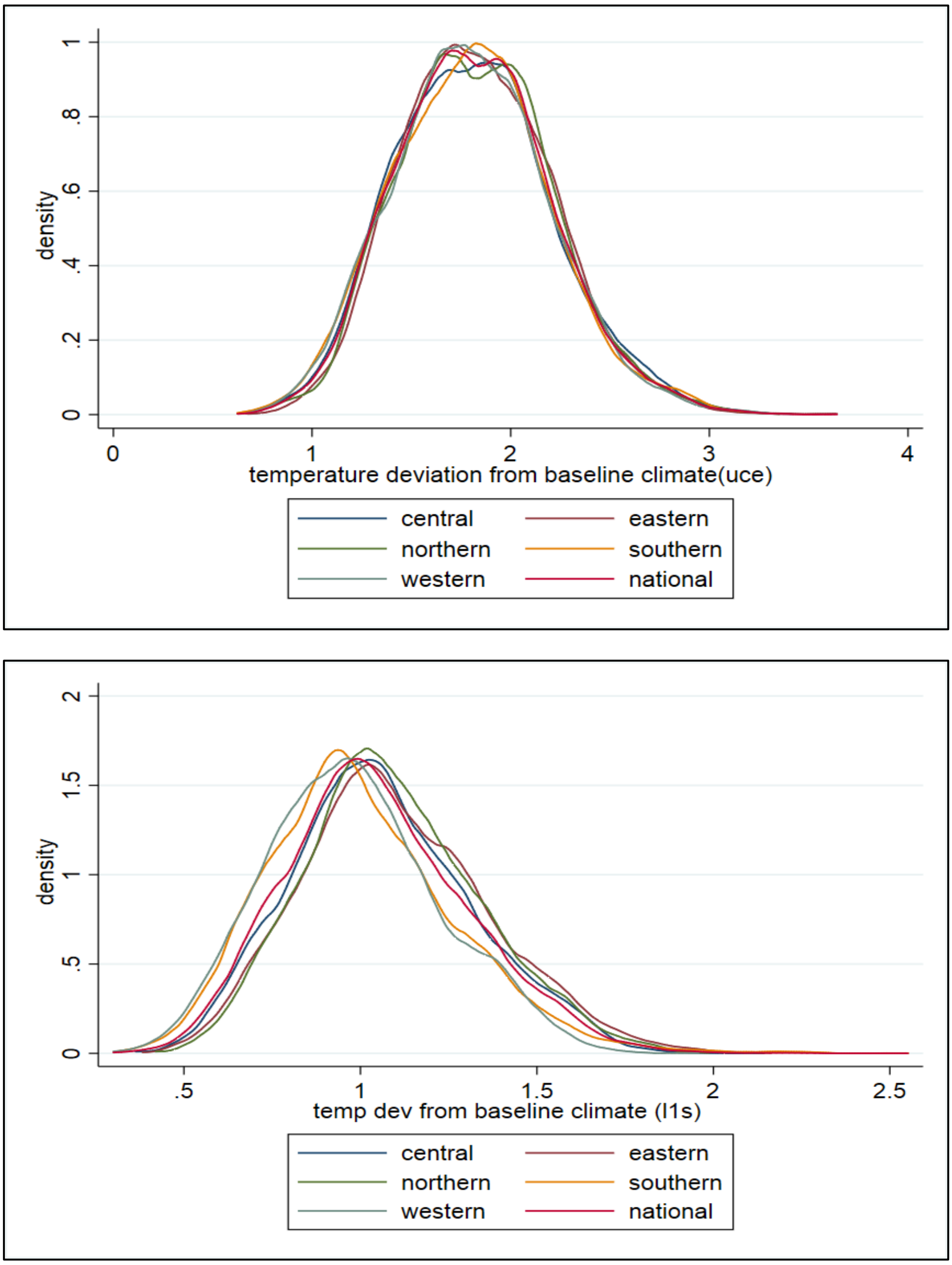

Figure 4: Regional level deviations in temperature under unconstrained emissions (top panel) and level one stabilization (lower panel) , 2046 - 2050

4.1.3 Impacts of climate change on crop yields

This subsection presents results on the impacts of climate change on key crop yields by region for each crop (Table 1 and Figure A2). According to the 2007 social accounting matrix used in this analysis, these crops account for just over 70% of the total agricultural crop production in Zambia (Chikuba et al 2013).

Table 1 highlights several key findings. First, climate change will on average reduce the yields of maize, other cereals, root crops and tobacco up to the end of the study period in 2050, with appreciable differences in the impacts of climate change on these crops. Second, maize is projected to be the crop worst affected by climate change, with estimated yield reductions of up to 4–6 percent in the worst-affected southern and western regions. However, maize productivity is likely to be less affected (< 2 percent) in the central and northern regions, which account for 50–60 percent of total maize production in the country (Chikuba et al 2013; CSO/MAL/IAPRI 2015). Third, cotton on the other hand is projected to be less adversely affected by climate change. In fact, cotton yields are projected to increase by 1% in the northern regions by 2050. It is difficult to read a great deal into the results for other cereals, because this category includes several crops such as wheat, barley and rice, making it difficult to isolate the impacts of climate change on any one of them. Suffice to mention, there are notable inter-regional differences in the impacts of climate change on the yields of wheat, barley, millet, rice, etc., across the five regions. Finally, the opposite is found with root crops, which, under the UCE scenario, experience a median increase of 0.50 percentage points in productivity relative to the baseline scenario in the northern region, although the range of outcomes is broad-ranging – between -9.4 percentage points and 5.7 percentage points (Table 1).

The largest negative climate change impacts on yields are expected to take place in the southern and western regions, which account for roughly 26% of agriculture value added. Here, large uncertainties of the level of impact are also highlighted (see differences between the minimum and maximum values). Cotton is the least affected by climate change. In the UCE global climate future, cotton experiences an increase in crop productivity across most regions, and these gains are maintained in the northern and central regions under L1S. Cotton also experiences the smallest levels of uncertainty with regards to the level of impact. In sum, it is found that climate change impacts on crop yields are less uncertain under the L1S scenario than under UCE. This is the case generally across crops and regions, because there is less uncertainty in temperature, precipitation, and evaporation changes under L1S.

Table 1: Regional level impacts of climate change on crop yield under unconstrained emissions and level one stabilization scenarios, 2046–2050.

	Unconstrained emissions scenario				Level one stabilization scenario			
	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median
Maize yield								
Central	-16.23	18.20	-1.39	-1.81	-11.38	9.37	-2.01	-1.98
Eastern	-13.30	17.92	-0.07	-0.07	-7.30	12.65	0.78	0.56
Northern	-9.99	7.93	-0.63	-0.41	-8.72	4.43	-0.86	-0.70
Southern	-21.89	25.98	-3.39	-4.36	-13.44	14.61	-4.11	-4.19
Western	-30.52	16.91	-6.40	-5.90	-20.46	7.06	-4.57	-4.32
Cotton yield								
Central	-5.60	5.54	-0.47	-0.44	-2.51	3.03	-0.29	-0.38
Eastern	-4.43	4.97	-0.20	-0.09	-1.61	3.21	0.53	0.56
Northern	-3.46	4.57	1.29	1.38	-1.43	3.58	0.96	0.95
Western	-5.51	3.67	-1.25	-1.31	-2.50	2.68	-0.87	-0.97
Other cereal yield								
Central	-8.30	6.62	-1.78	-1.84	-4.94	2.61	-1.81	-1.81
Eastern	-6.93	5.34	-0.95	-0.90	-4.45	4.37	-0.90	-1.16
Northern	-4.91	2.61	-1.18	-1.18	-2.95	3.24	-0.62	-0.78
Southern	-11.01	11.47	-2.11	-2.39	-7.08	6.00	-2.34	-2.34
Western	-13.13	7.49	-3.31	-3.13	-6.43	1.74	-3.43	-3.50
Root crop yield								
Central	-11.03	11.32	-1.49	-1.74	-8.97	5.58	-1.97	-2.05
Eastern	-13.77	16.05	-3.17	-3.50	-7.96	5.43	-2.34	-2.36
Northern	-9.44	5.71	0.44	0.50	-8.90	2.44	-0.90	-0.75
Southern	-16.31	9.19	-4.38	-4.30	-8.51	3.71	-4.32	-4.42
Western	-18.78	11.18	-3.65	-3.68	-10.79	3.62	-4.28	-4.31
Tobacco yield								
Central	-7.37	7.27	-1.88	-2.14	-7.27	2.35	-1.79	-1.74
Eastern	-7.70	11.78	-1.34	-1.47	-6.41	3.72	-1.51	-1.34
Northern	-6.15	3.81	-1.13	-1.17	-3.49	2.18	-0.90	-0.87
Southern	-20.97	6.89	-3.67	-3.43	-8.60	2.60	-2.68	-2.60
Western	-21.97	6.95	-4.44	-3.61	-14.97	3.67	-2.95	-2.71

5 ECONOMIC RESULTS

This section presents economic results from the economy-wide modelling for both UCE and L1S scenarios. It reports the macroeconomic effects of climate change on economic development and household welfare using only the agricultural impact channel. Results are presented at national level for each for the average last five years of the model period. For the case of total GDP, the results are also presented for each of the four decades between 2011 and 2050. Agriculture impacts are presented at the regional level as well. Detailed results are presented in Table A2.

5.1.1 Impacts of climate change on GDP

The impacts of climate change on the general economy under the UCE and L1S scenarios are presented in Figure 5. Impacts are measured as the ratio relative to the baseline scenario where global emissions continue to increase. As such, a value >1 implies an increase in the level of GDP relative to the baseline scenario, and a value of <1 implies the converse. The results show that climate change is likely to reduce GDP under both the UCE and L1S global futures. Based only on the agricultural impact channel, climate change marginally reduces GDP by 1.00 percent (mean) under the UCE scenario. There were no large differences found in the mean impacts of climate change on GDP under UCE or L1S, but outcomes under UCE are more uncertain.

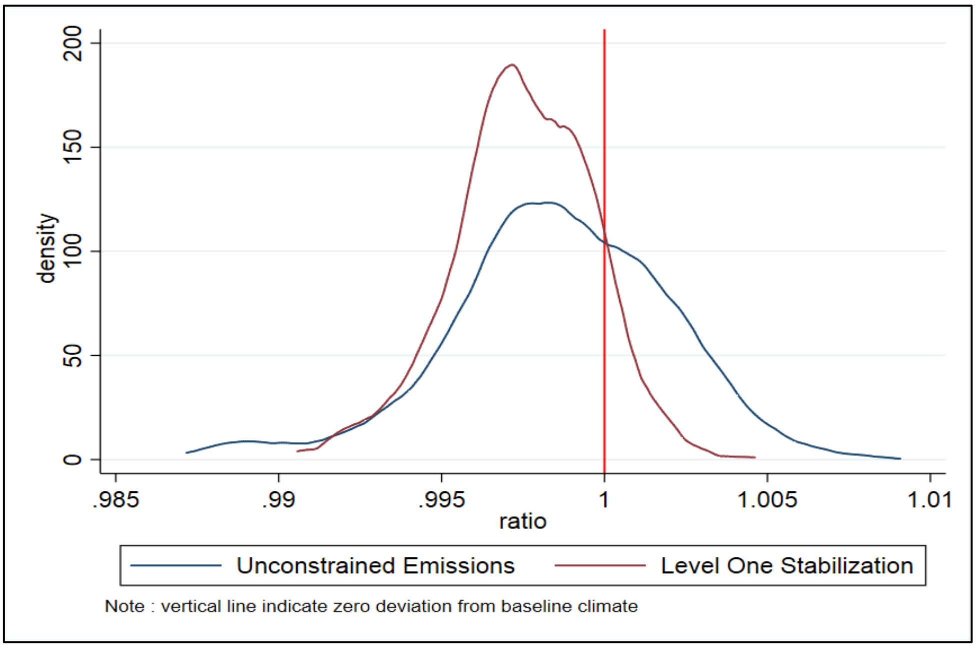

Figure 5: National level impacts of climate change on total GDP under unconstrained emissions and level one stabilization, 2046–2050.

Decadal results presented in Figure 6 give a more nuanced picture on the impacts of climate on GDP between 2011 and 2050. While climate change is projected to reduce GDP throughout the four decades, the negative impacts are progressive with time, as is the uncertainty of these impacts. For example, the impact of climate change on GDP in the first decade (2011-2020) deviates only by a smaller margin from unity when compared to the fourth decade (2041 -2050). Thus, climate change is expected to progressively reduce GDP over time in Zambia. Readers are referred to Tembo et al (forthcoming) for more details on the cumulative impacts of climate change on economic growth.

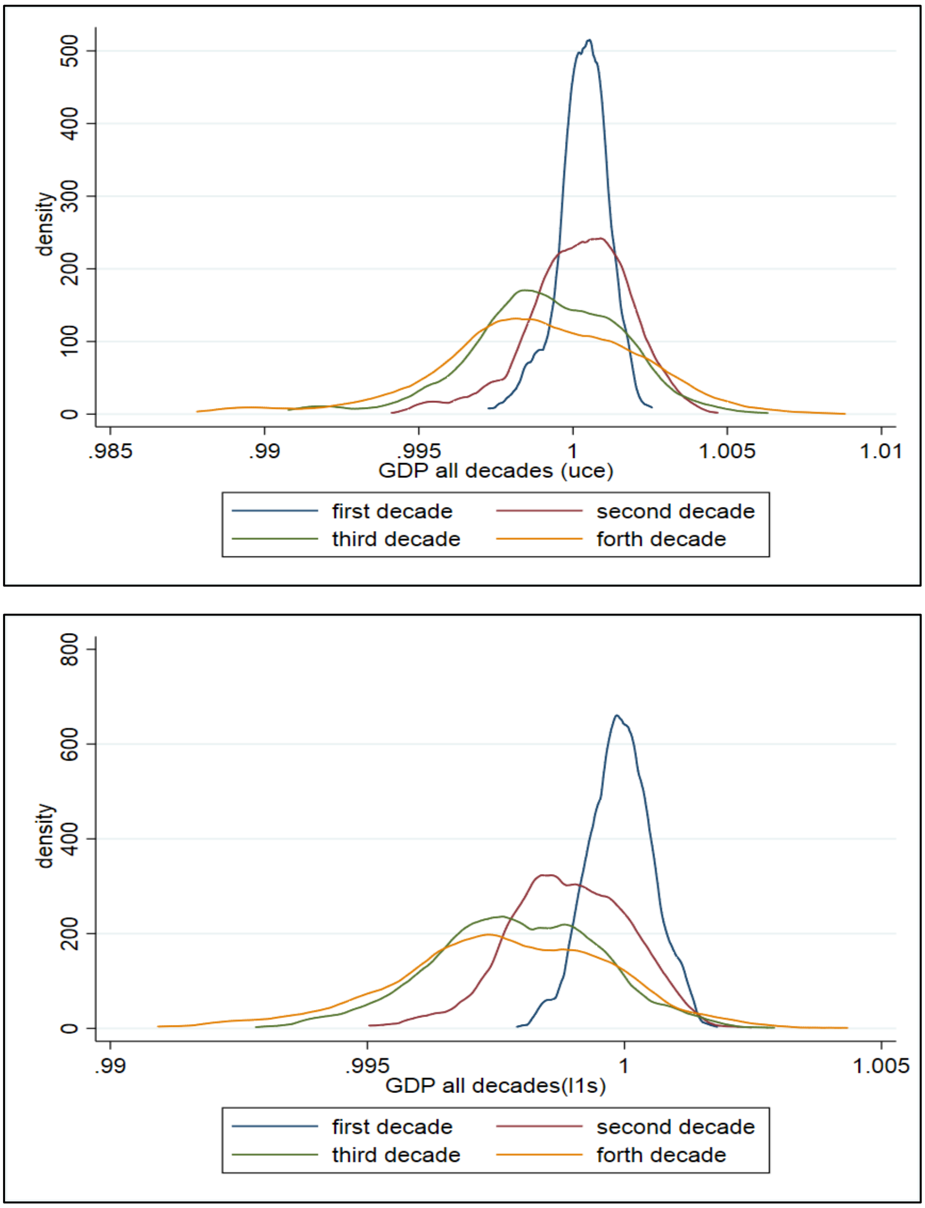

Figure 6: Impacts of climate change on total GDP by decade under unconstrained emissions (top panel) and level one stabilization (bottom panel) scenarios between 2011 and 2050.

5.1.2 Impacts of climate change on agriculture's share in GDP

Results shown in Figure 7 suggest that, on average, climate change likely reduces the share of agriculture in GDP between 2046 and 2050. While the median decline in agriculture's share is similar under UCE and L1S, the range of uncertainty is narrow with global mitigation efforts, as the variability in climatic changes is smaller under L1S.

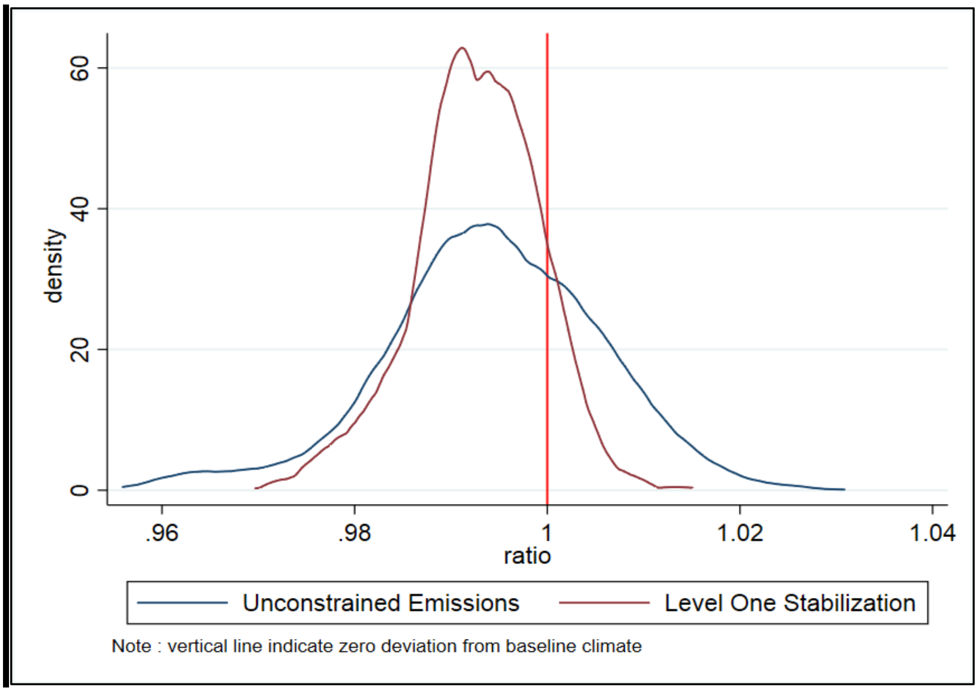

Figure 7: Impacts of climate change on total agriculture share to Gross Domestic Product under unconstrained emissions and level one stabilization over a five-year period from 2046 to 2050.

As was the case with GDP, the cumulative impacts of climate change on agriculture share in GDP are more progressive, with larger impacts in the fourth decade, between 2041 and 2050.

5.1.3 Impacts of climate change on agricultural production

Figure 8 presents the impacts of climate change on agricultural production by crop. Maize and root crops are key in Zambia and account for more than 50% of total gross value added in agricultural production. Results show that climate change negatively affects both maize and root crop production. Overall, agricultural production declines over time under the UCE and L1S at the national level for maize, other cereals, root crops and tobacco (Figure 8). Cotton production appears less affected by climate change at the national level.

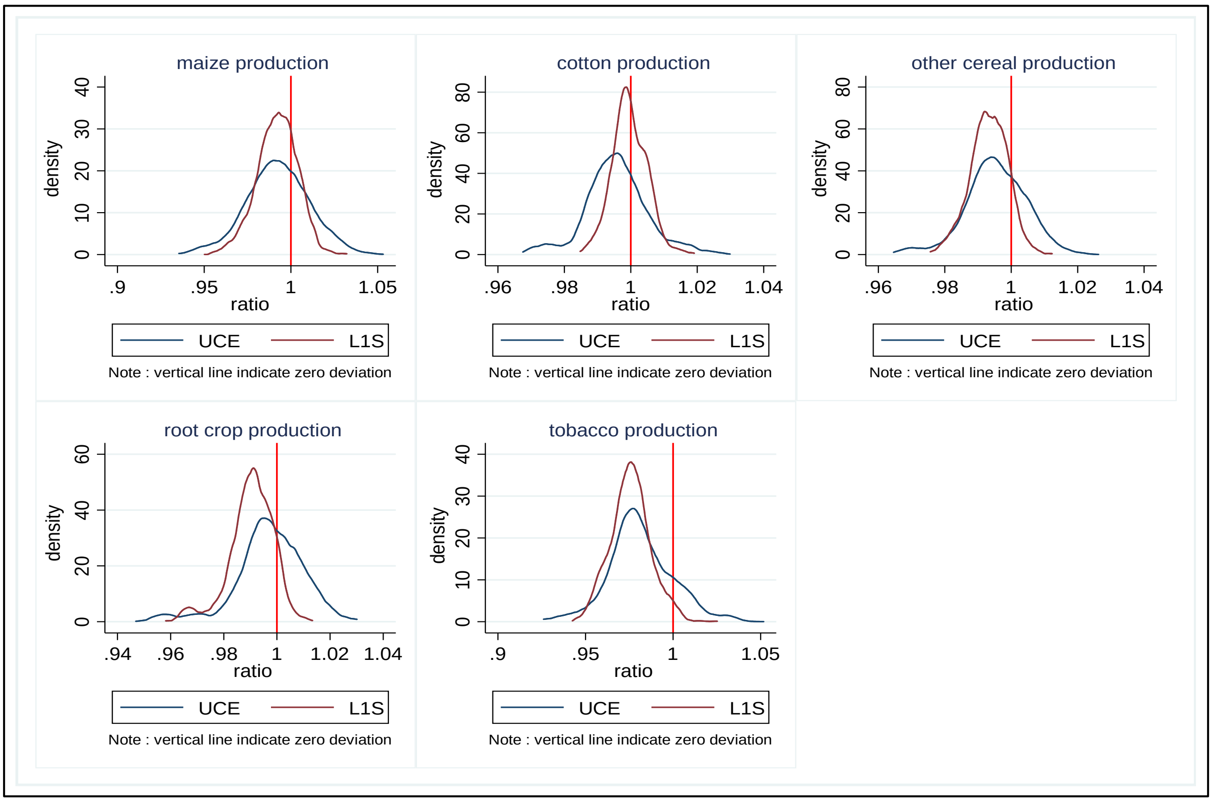

Figure 8: National level impacts of climate change on maize (top left panel), cotton (top mid panel), other cereal (top right panel), root crops (bottom left panel) and tobacco (bottom mid panel) production under unconstrained emissions and level one stabilization scenarios, 2046–2050

Table 2 presents results on the impacts of climate change on production for specific crops and by region. These results highlight two main nuances (readers are referred to Table A1 in the appendix for detailed national crop level results). First, among the five crops considered, climate change is projected to reduce production of maize much more than of any other crop by 2050. Cotton production is least affected by climate change, with some marginal increase projected in some regions, e.g. eastern under L1s. Second, the impacts of climate change will differ by region with the southern and western regions projected to be the worst affected for crops such as maize. Compared to the northern region, southern and western regions are also projected to have the largest uncertainties associated with the impacts of climate change on crop production (see minimum and maximum values for each region). Therefore, production resources shift out of these southern and western regions, where possible, and into the northern, eastern and central regions. When adding in the other impact channels, particularly roads and energy, the impacts on agriculture become more negative on the various crops, especially maize and root crops, with the distribution shifting to the left.

Table 2: Crop and regional level impacts of climate change on crop production under unconstrained emissions and level one stabilization scenarios, 2046–2050.

	Unconstrained emissions scenario				Level one stabilization scenario			
	Mean	Median	Min	Max	Mean	Median	Min	Max
Maize production								
Central	0.99	0.98	0.89	1.11	0.97	0.98	0.91	1.04
Eastern	1.01	1.01	0.92	1.12	1.04	1.03	0.97	1.13
Northern	1.00	1.01	0.91	1.07	1.00	1.00	0.95	1.03
Southern	0.96	0.94	0.80	1.22	0.95	0.95	0.85	1.09
Western	0.91	0.92	0.61	1.15	0.93	0.93	0.73	1.08
Other cereal production								
Central	0.99	0.99	0.93	1.08	0.98	0.98	0.94	1.03
Eastern	1.02	1.01	0.96	1.09	1.01	1.00	0.97	1.09
Northern	1.01	1.01	0.96	1.04	1.01	1.01	0.98	1.06
Southern	0.98	0.97	0.90	1.13	0.97	0.97	0.92	1.07
Western	0.96	0.96	0.79	1.08	0.95	0.95	0.89	1.00
Root crop production								
Central	0.97	0.96	0.88	1.10	0.98	0.98	0.93	1.05
Eastern	0.92	0.91	0.79	1.18	0.97	0.96	0.91	1.09
Northern	1.01	1.01	0.96	1.04	1.00	1.00	0.96	1.02
Southern	0.89	0.90	0.75	1.09	0.92	0.92	0.86	1.03
Western	0.93	0.92	0.79	1.11	0.93	0.93	0.87	1.00
Tobacco production								
Central	0.99	0.99	0.95	1.08	0.98	0.98	0.95	1.03
Eastern	1.00	1.00	0.94	1.10	0.99	0.99	0.95	1.04
Northern	1.01	1.01	0.96	1.08	1.00	1.00	0.97	1.03
Southern	0.96	0.96	0.80	1.09	0.96	0.96	0.90	1.03
Western	0.95	0.96	0.74	1.07	0.96	0.96	0.85	1.03
Cotton production								
Central	1.00	1.00	0.95	1.06	0.99	0.99	0.97	1.03
Eastern	1.00	1.00	0.98	1.04	1.01	1.01	0.99	1.03

Southern	0.97	0.97	0.93	1.02	0.98	0.98	0.95	1.01

5.1.4 Impacts of climate change on total household expenditure

Results on the impacts of climate change on total household expenditure at the national level are shown in Figure 9. Household expenditure is used as a measure of household welfare. Results suggest that climate change is projected to reduce household expenditure, and the uncertainty of the impacts are larger under UCE than L1S during the 2046–2050 period.

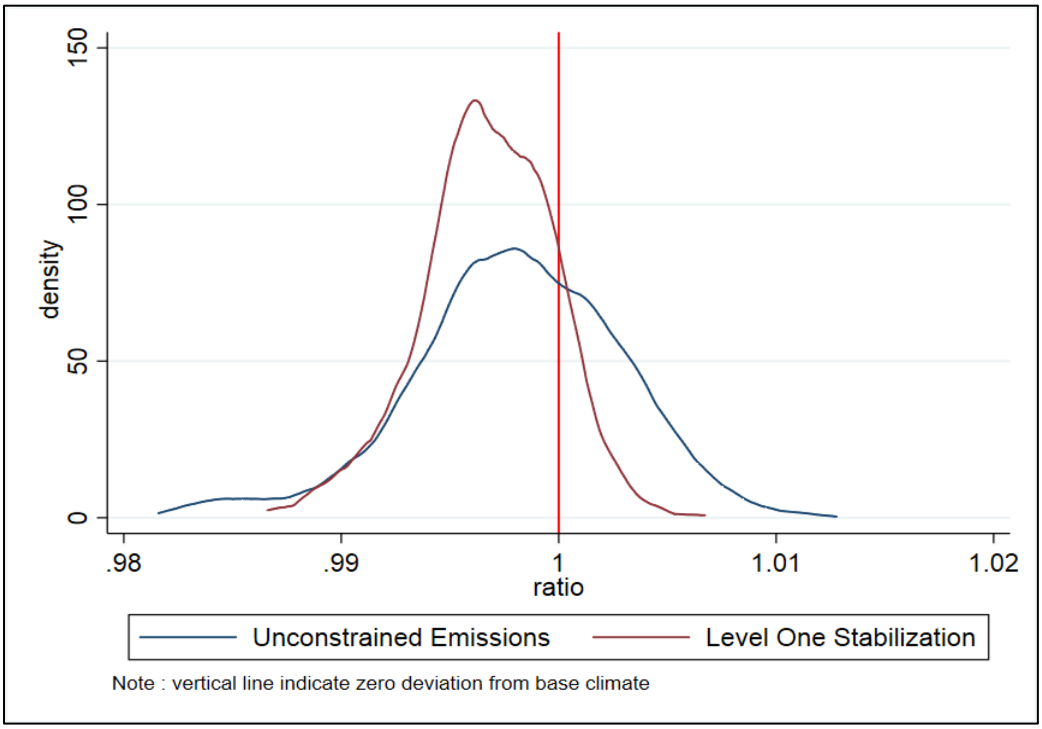

Figure 9: Impacts of climate change on total household expenditure under unconstrained emissions and level one stabilization, 2046–2050.

As would be expected, the impacts of climate change on household expenditure are larger and more uncertain in the furthest distant, fourth, decade (2041–2050) when compared to the current decade (2011–2020) in the highest quintiles (Figure 10) and among urban consumers (Figure 11).

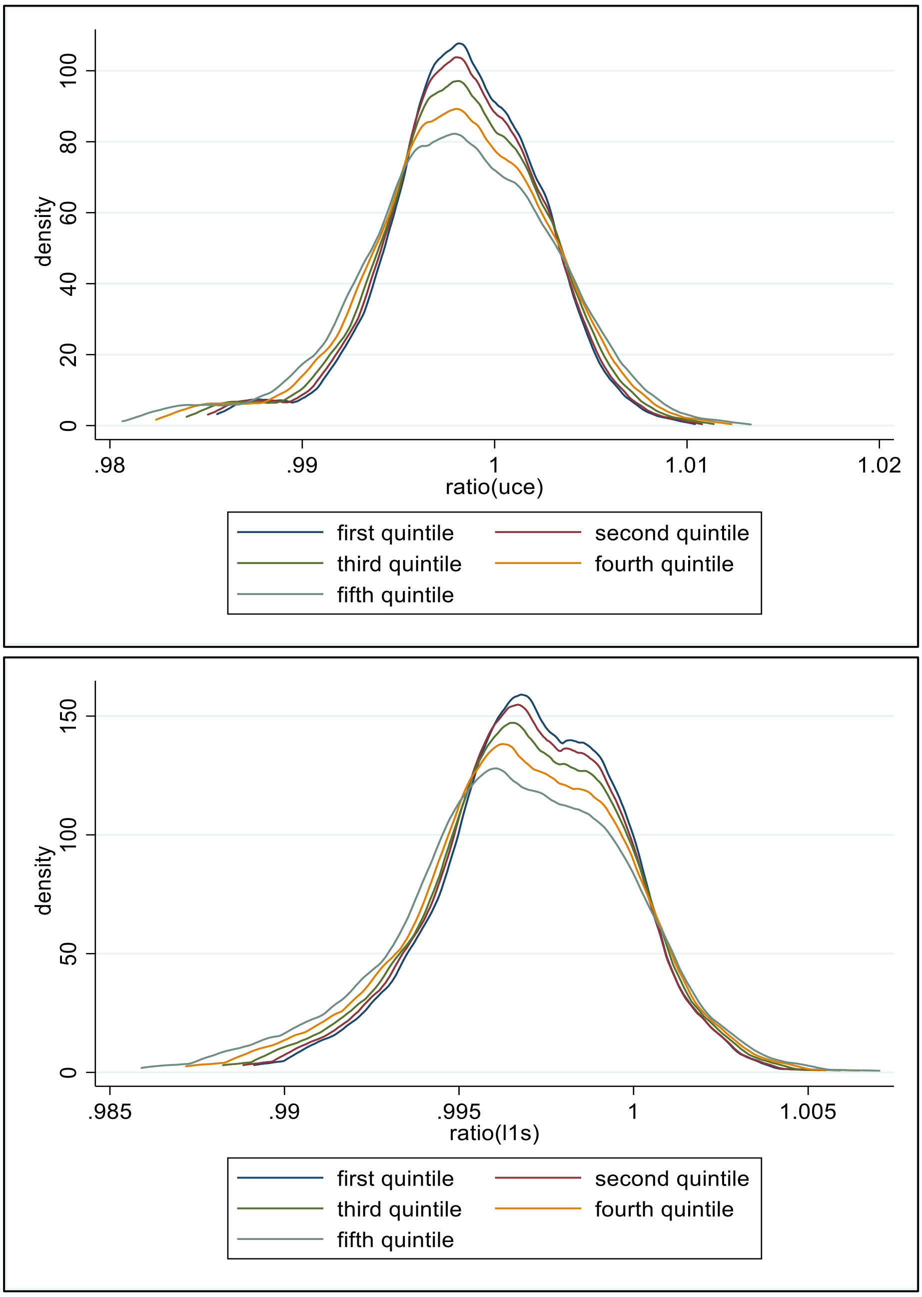

Figure 10: Impacts of climate change on total household expenditure under unconstrained emissions (top panel) and level one stabilization (bottom panel) by quintile, 2011–2050.

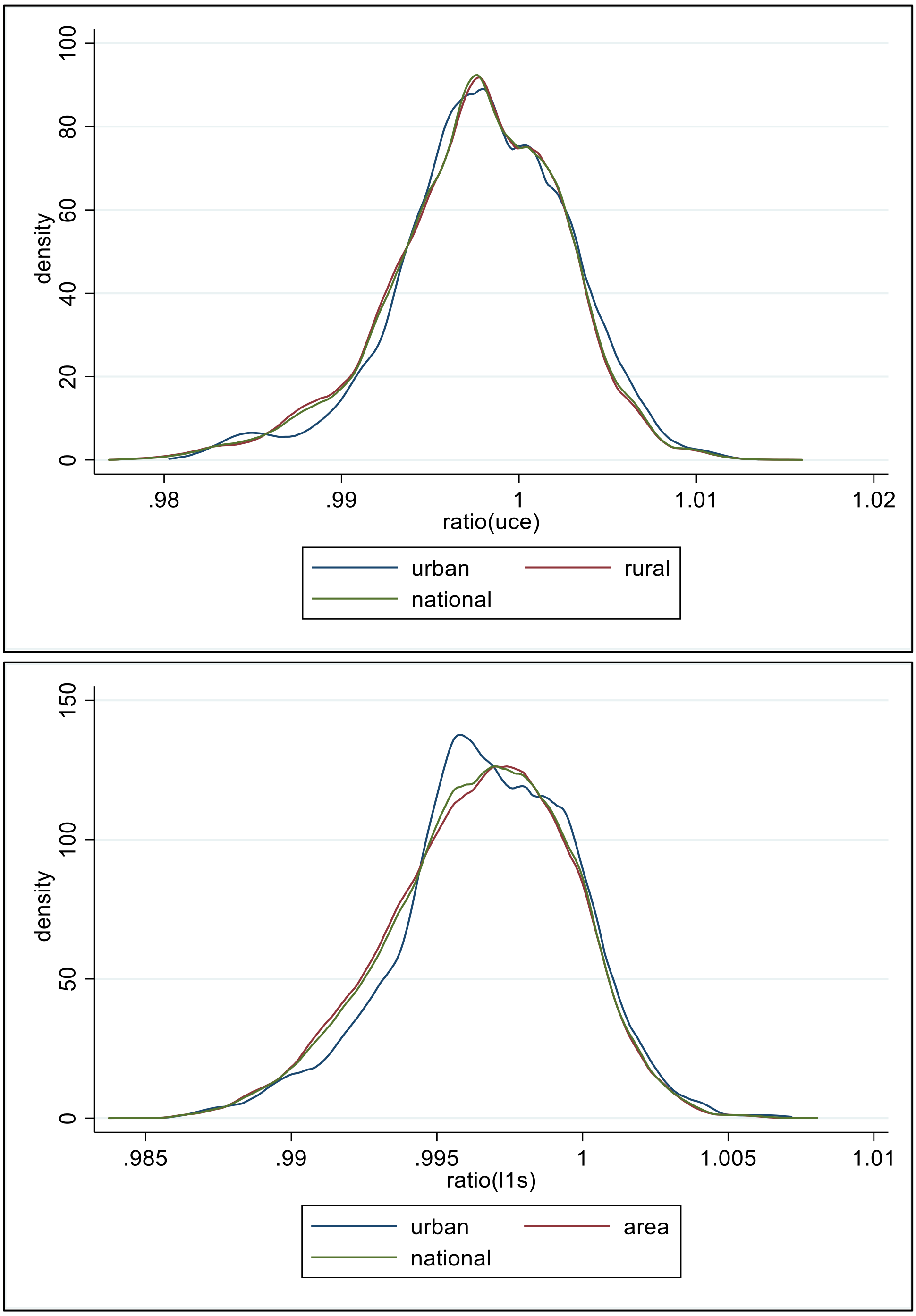

Figure 11: Impacts of climate change on total household expenditure under unconstrained emissions (left panel) and level one stabilization (right panel) by urban and rural area , 2046–2050.

5.1.5 Impacts of climate change on agricultural trade balance

Climate change is projected to reduce net agricultural exports at national level (Figure 12). The reduction in net exports will be larger under UCE than L1S, as can be seen from the larger distribution of extreme values under the former than the latter, but the magnitude of the effects based only on the agricultural channel are small. The impacts of climate change under UCE are also associated with larger uncertainty.

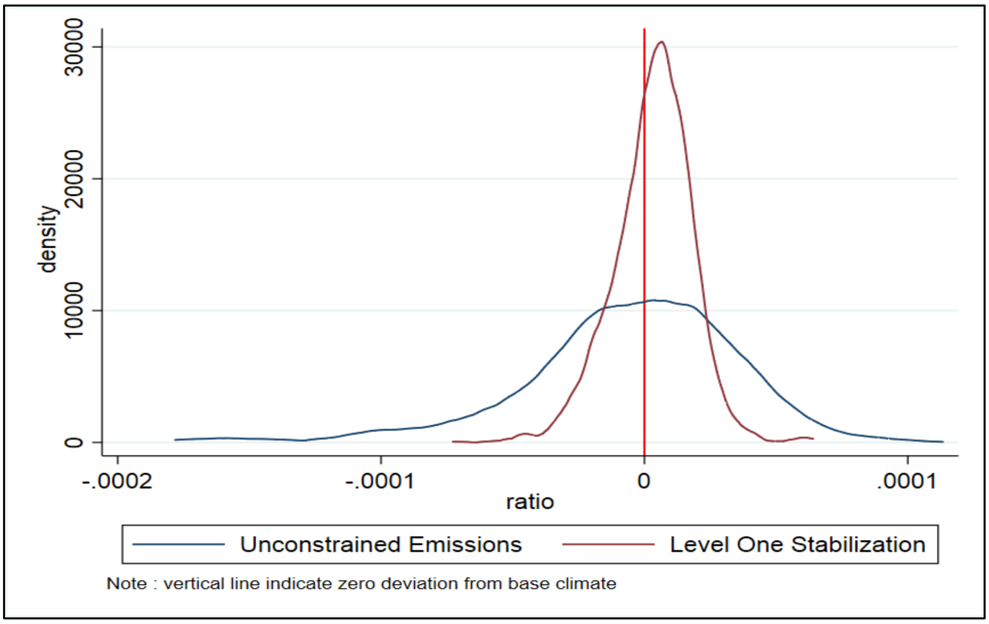

Figure 12: National level impacts of climate change on net exports under unconstrained emissions and level one stabilization, 2046–2050.

6 DISCUSSION

6.1 Impacts of climate change on crop yields and production

In line with previous research by Thurlow et al. (2012) and Hamududu and Ngoma (2019), the present study's results suggest that Zambia is likely to experience hotter temperatures and reduced rainfall by the end of the period covered in this study (ie, by 2050) and climate change is likely to reduce crop yields both under UCE and L1S climate change futures. At both national and regional levels, results suggest that the impacts will become progressively worse as the impacts of climate change are increasingly felt. These results corroborate Arndt et al. (2014), who found that climate change effects become more negative and begin to impede overall prospects of economic growth between the 2030s and 2040s. The present results also show that maize is the crop most vulnerable to climate change. This is in line with other studies showing that maize will have the highest productivity losses, due to rainfall variability and temperature increases (IPCC, 2019; Verhage et al., 2019; GRZ, 2016a). Similarly, Mulenga et al. (2015) found that future climate patterns would substantially reduce maize yields over time in Zambia. The present study also found that, in the absence of any global mitigation efforts, crop yields will likely reduce more significantly. At the regional level, the southern and western regions will be the worst affected by climate change, a result in agreement with Hamududu and Ngoma (2019), who found that climate change will significantly reduce water availability in these regions by mid-century.

Cereal crops (wheat and maize) are the top two staple foods and provide 63 percent of the energy requirements in Zambia (Mwanamwenge and Harris, 2017; Chapoto and Sitko, 2015). Thus, results in this paper have important implications for national food security and agricultural incomes. To ensure food security and improved household welfare, there is a need to facilitate access to irrigation facilities for smallholder farmers to increase crop yields, diversify production, and encourage a shift from rain-fed crop production. The lower yield reductions for cotton, other cereals, root crops, and tobacco corroborate the need to diversify production away from maize to lessen the risks of climate-induced crop failure and food insecurity in Zambia.

Of the five regions, the southern and western were most vulnerable to climate change. In these regions, climate change is projected to negatively affect crop production and productivity through to 2050. To some extent, this result would be expected: these regions are located in agro-ecological region one, which receives low rainfall, and are therefore vulnerable to climate change and variability. The potential effects were larger under the unconstrained emissions scenario, suggesting that global climate mitigation policy options – if achieved – can yield positive effects in agriculture.

In general, Zambia is witnessing a shift in agricultural production towards the Northern regions. For example, the northern and central regions accounted for about 52 percent of maize production during the 2014/2015 season, while the southern and western regions accounted for 27 percent (CSO/MAL/IAPRI, 2015). This shift is partly driven by the fact that the northern region seems to benefit under climate change – although there are scenarios under which the region is negatively impacted. Maize production increases in the region by shifting labour and capital into maize to offset the decline in yield and to take advantage of the relatively higher output prices. At the same time, some root crop production also increases. The combined negative impact of climate change on crop production in other regions, such as in central, southern and western, is the key driver of the decline in total agriculture value added. With regard to the eastern region, it is more likely to experience a positive impact in agriculture value added, although negative impacts are also possible. The negative effects of climate change on crop yields in the eastern region are not as large as in the central region.

6.2 Impacts of climate change on economic development and household expenditure

The study's results mainly suggest that climate change is likely to reduce total GDP and household expenditure and that changes in GDP are more nuanced under the UCE compared to the L1S scenario in Zambia. These results are in line with prior work in Southern Africa (Arndt et al., 2011; Arndt and Thurlow, 2013; Cullis et al., 2015), which also find that climate change is expected to negatively affect economic growth and development, especially without global mitigation. The negative effects of climate change on economic development are progressive with time and become more pronounced in the fourth decade (2041-2050), as compared to the first two decades between 2011 and 2030. The findings are also in line with Thurlow et al. (2012), who found that climate change will reduce GDP and increase the poverty incidence in Zambia. Thus, it can be deduced from this study's findings that climate change is likely to exacerbate poverty among households, especially those in rural areas that depend on rain-fed agriculture for their livelihoods.

6.3 Impacts of climate change on agriculture trade balance (net exports)

Agricultural trade provides a wide range of consumable goods and plays a crucial role in combating food and nutrition insecurity worldwide. The present results suggest that net agricultural exports will likely reduce over time due to climate change. The future climate uncertainty reduces agricultural productivity in the country, causing crop yields to dwindle, thus creating a shortage of domestically produced food. This may also negatively affect revenue generated from export of food commodities. In line with this, Ludi et al. (2007) suggest that poverty in rural areas will rise because of decreasing agricultural exports.

Because the impacts of climate change will vary across crops and regions in Zambia, and depending on whether there are mitigation efforts or not, locally adapted climate actions are needed. Climate actions supported by the private sector and donor communities are required at national and subnational levels. These findings suggest that the full range of climate impacts are progressive with time, presenting a window of opportunity to plan, develop and implement smart, forward-looking policies that will appropriately address the climate change impact pathways (Arndt et al., 2014). In agriculture, stepping-up, scaling-out and scaling-up of climate-smart agriculture in order to reduce emissions, while increasing food production to meet rising food demands, offer opportunities for Zambia. Investments in climate-smart smallholder irrigation is key. As Hertel et al., (2018) suggest, shifts in comparative advantages in agricultural trade requires rethinking of regional trade and production patterns in order to assure household welfare in global south countries like Zambia.

Readers should bear in mind that the results of this study, showing that, on average, climate change is likely to negatively affect agriculture, economic and welfare in Zambia, should be taken as lower bound estimates since they are only based on the agricultural impact channel. The cumulative impacts of climate change through, for example, agriculture, infrastructure and energy, are larger (Tembo et al., forthcoming).

7 CONCLUSION

The study used data from global circulation models (GCMs) based on 819 future climate projections and a dynamic computable general equilibrium model to assess the biophysical and economic impacts of climate change on crop yield and production, GDP, household expenditure and agricultural trade in Zambia. It also assessed likely changes in rainfall and temperature. The analysis covered the period 2011–2050, but the paper reports results for the period 2046 to 2050, to account for the fact that climate change impacts are progressive. Outputs from GCMs are used as inputs in biophysical models, which eventually compute the outputs that are used in the economy-wide modelling. This study focused on five different crops or crop-types, namely maize, other cereals (wheat, barley, rice, etc.,), root crops (such as cassava and potatoes), and the non-traditional crops cotton and tobacco. The CGE model was calibrated using a 2007 social accounting matrix for Zambia.

Overall, rainfall is projected to reduce by 0.87 percentage points at national level, and by between 3 and 4 percentage points in the worst affected southern and western regions by 2050. Over the same period, temperature is projected to increase by 1.82°C. These changes in rainfall and temperature will likely lead to progressive declines in crop yield and production, with maize expected to be the hardest hit. Based only on the agricultural channel, climate change will likely reduce the national GDP and share of agriculture contribution to GDP. It is also expected to reduce net agricultural exports at national level and reduce household expenditure.

At the regional level, the southern and western regions are projected to have the most substantial negative impacts of climate change on crop yield and production, meaning that they will become progressively more vulnerable over time. Three main implications can be drawn from the findings presented in this paper.

- First, the projected increases in temperature and reductions in rainfall imply that reliance on rain-fed production systems prevalent in Zambia may be untenable. There is an urgent need to invest in efficient and cost-effective small-scale irrigation schemes and scaling-up adoption of region-specific drought- and heat-tolerant crop varieties.
- Second, maize – the national staple crop – is projected to be the crop worst affected crop by climate change, reinforcing the need for diversified production. Crop diversification has been championed for many years in Zambia, but is yet to be actualized. There is need for investments in market development, extension services and market-driven production support/incentive systems for alternative crops that are suitable in the specific regions of Zambia.
- Third, the progressive and cumulative nature of the expected impacts and, on average, the lower impacts under the level one stabilization (L1S) scenario, present opportunities to take action now to reduce the projected negative impacts in the next 30 years. Since Zambia is already experiencing the negative effects of climate change on agriculture – as seen during El Nino events and the successive droughts in previous seasons that led to crop failure and dramatic changes in GDP contribution share by the agricultural sector – this evidence can be used to nudge politically backed climate action.

The study results show that, if mitigation efforts within the agricultural sector and at the global level are not scaled-up, GDP and agriculture contributions to it will continue to decline. This will have dire consequences for the country, as many people depend on the agricultural sector for their livelihoods and nutrition outcomes. This is not an easy route, because cooperative global mitigation efforts are needed to actualize outcomes under L1S. There are several promising local level interventions that can add to the global environmental good. For example, mitigation actions within the agricultural sector can be scaled-up by promoting and nudging the adoption of climate-smart agriculture. At policy level, there is need for better coordination between forestry and agriculture through integrated land use planning to ensure that land converted to agriculture does not have high biodiversity and environmental costs. This is important to reconcile forest conservation and food production and limit greenhouse gas emissions. And, lastly, there is an urgent need to raise public financial support to environmental protection in national budgets because the current allocations are too low.[8]

[8] Trends and current allocations to agriculture and environmental protection can be seen in these papers: Chisanga et al. (2018), Kabisa et al. (2019), Mabeta et al. (2018), Mweemba (2018), and Mulenga et al. (2019b).

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APPENDIX

Table A1: National level impacts of climate change on crop yields and expected changes in rainfall and temperature under unconstrained emissions and level one stabilization, 2046–2050.

	UCE				L1S			
	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median
Biophysical results								
Rainfall	-31.36	35.67	0.66	0.96	-16.76	18.66	-0.87	-1.04
Temperature	0.62	3.64	1.82	1.80	0.30	2.55	1.05	1.03
Economic results								
GDP	0.99	1.01	1.00	1.00	0.99	1.00	1.00	1.00
Agriculture share of GDP	0.96	1.03	0.99	0.99	0.97	1.02	0.99	0.99
Household expenditure	0.98	1.01	1.00	1.00	0.99	1.01	1.00	1.00
Net Exports	-0.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00
Maize production	0.94	1.05	0.99	0.99	0.95	1.03	0.99	0.99
Cotton production	0.97	1.03	1.00	1.00	0.98	1.02	1.00	1.00
Other cereal production	0.96	1.03	1.00	1.00	0.98	1.01	0.99	0.99
Root crop production	0.95	1.03	1.00	1.00	0.96	1.01	0.99	0.99
Tobacco production	0.93	1.05	0.98	0.98	0.94	1.03	0.98	0.98

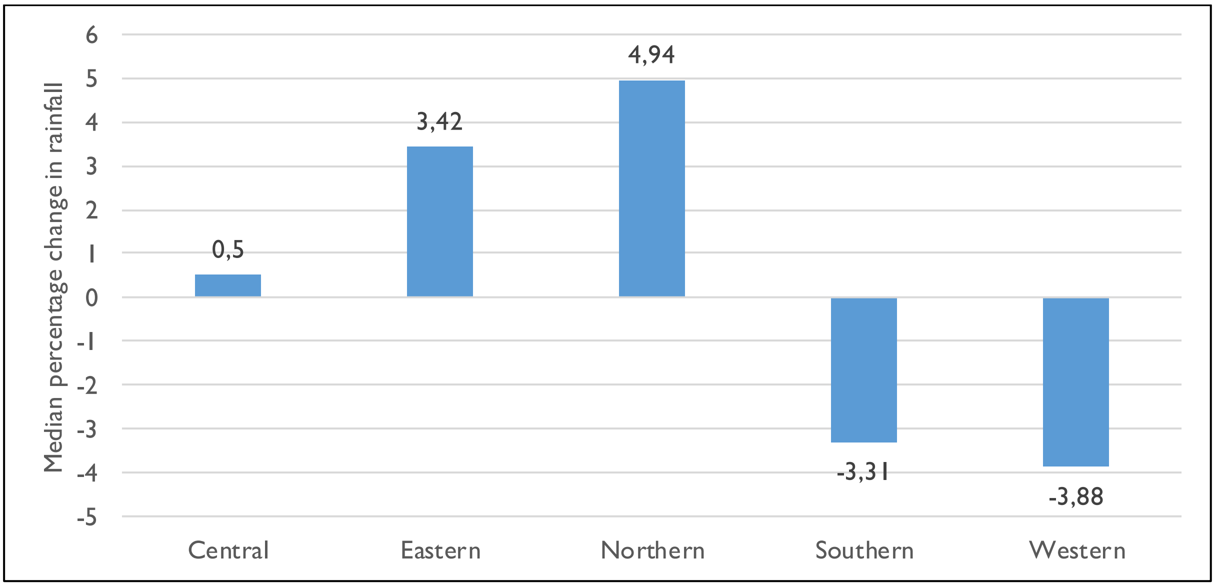

Figure A1: Projected regional level median percentage changes in rainfall under unconstrained emissions from 2046 to 2050.

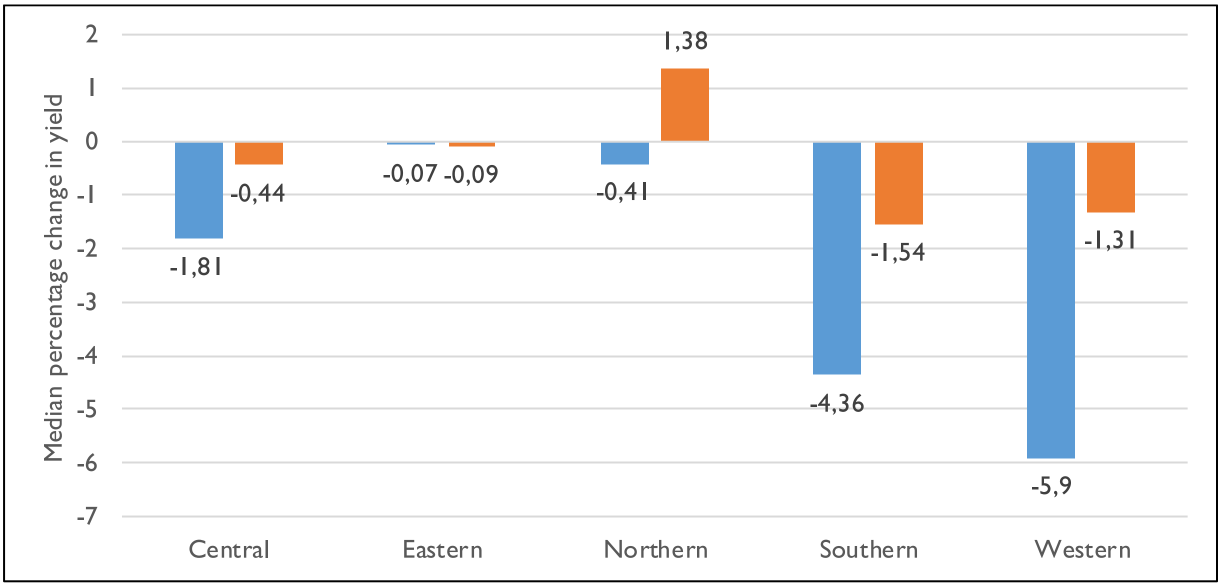

Figure A2: Projected climate change induced median percentage changes in maize and cotton yields under unconstrained emissions from 2046 to 2050 by region in Zambia.

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