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Impacts of climate change on agriculture and household welfare in Zambia: an economy-wide analysis

Hambulo Ngoma[1,2] · Patrick Lupiya[1] · Mulako Kabisa[1] · Faaiqa Hartley[3]

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Abstract
Rainfed agriculture is the primary impact channel for agrarian economies like Zambia, but it is uncertain how future climate will be and by how much it will affect agriculture, household welfare, and economic growth. We use an integrated framework that combines climate models, biophysical models, and an economy-wide computable general equilibrium model based on a 2007 Social Accounting Matrix to assess the impacts of climate change on agriculture, economic growth, and household welfare in Zambia. We address the uncertainty associated with climate change by using data from the general circulation models based on 819 potential future climate scenarios. There are three main results. First, rainfall is projected to decline with the Southern and Western regions of Zambia worst affected, and temperature is projected to increase by 2050. Second, climate change is projected to reduce crop yield and production, with maize expected to be the hardest hit. These impacts are progressive over time. And lastly, based only on the agricultural impact channel, climate change will likely reduce national gross domestic product (GDP), agricultural production, and household welfare. There are significant regional differences, with the Southern and Western regions projected to bear the most substantial negative impacts of climate change on crop yield and production. These findings have implications for targeting of adaptation interventions needed to sustain the future of smallholder agriculture in Zambia.

Keywords CGE models · Climate change · Welfare · Zambia

JEL classification C68 · Q54 · Q15 · I32

✉ Hambulo Ngoma
h.ngoma@cgiar.org

1 Indaba Agricultural Policy Research Institute, Lusaka, Zambia

2 Present address: International Maize and Wheat Improvement Center (CIMMYT), Harare, Zimbabwe

3 University of Cape Town, Cape Town, South Africa

1 Introduction

Now more than ever, there is a consensus that the world's climate system has changed due to human activities. These changes are occurring in both natural ecosystems and human well-being, with the poor and those already grappling with food insecurity expected to be hardest hit (De Pinto et al. 2019, b; 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 the 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 who rely on agricultural production for their livelihoods (IPCC, 2018). This is because rainfed 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 nutritional outcomes (Meybeck et al., 2018). This calls for more and not less mitigation action.

A major challenge in dealing with climate change is its 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). Agriculture is an important economic sector in sub-Saharan Africa (SSA) where it is a source of livelihoods for over 50% of the labor force (OECD/FAO, 2016). Yet, the sector is the primary impact channel for climate change. In Zambia, agriculture employs over 22.3% of the labor force, and it is a source of livelihoods for over 50% of the population (ZamStats, 2019; GRZ, 2016a, b).[1] Its rainfed nature, however, exposes the sector to climate shocks and makes rural households vulnerable to climate change.

As articulated in national policies including the Seventh National Development Plan, the National Policy on Climate Change, and the Second National Agriculture Policy, it is critical for Zambia to understand how and where the impacts of climate change will be most felt in order to inform adaptation planning at the national and subnational levels (GRZ, 2016b; GRZ, 2016a; GRZ, 2017). There are some knowns already in Zambia where climate change is projected to increase the poverty gap, increase incidents of crop failure, change the length of the growing season, and lead to a 13% reduction in water availability by 2050 (Ngoma et al. 2019; Hamududu and Ngoma, 2019; Verhage et al. 2018; Mulenga et al. 2017). There are also suggestions that the impacts of climate change on Zambian agriculture will differ by agro-ecological region and that climate change may increase the need for crop diversification, reduce national GDP by 4%, and may have led to approximately 300,000 more poor people between 2007 and 2016 (Mulungu et al. 2021; Braimoh et al. 2016; Thurlow et al. 2012).

Despite the foregoing evidence on the impacts of climate change on agriculture in Zambia, gaps remain in understanding the likely impacts of climate change on agriculture and household welfare at subnational level and for different crops, and the resulting implications for adaptation planning. This subnational and crop level knowledge of the likely impacts of climate change on agriculture is important to inform agricultural production and development policies needed to mitigate and adapt to climate change and variability. Further, knowledge on the economic implications is important to guide antipoverty policies. There is a dearth of information at this granular level in SSA, more broadly. Not only do existing studies fail to adequately address the uncertainty associated with climate change, but they have also tended to focus mostly on changes in biophysical factors such as average temperatures and rainfall—with little attention given to the broader range of the potential economic impacts of climate

[1] 22.3% of Zambians are employed in agriculture, forestry, and fishing sectors.

change on agricultural production, economic growth, and household welfare (De Pinto et al. 2019, b).[2]

This paper contributes towards filling these gaps and assesses the potential impacts of climate change on agriculture, economic growth, and welfare at subnational levels, and for various crops. We complement existing literature in two ways. First, while this study is similar to other studies that combine biophysical and economic models in evaluating the impacts of climate change on agriculture at both national and regional levels (e.g., Thurlow et al. 2012; Mulungu et al. 2021), we add to these studies (i) by focusing only at regional level; (ii) we include more crops (five types) than previous studies and; (iii) we account for the uncertainty of climate outcomes by using 819 potential climate scenarios.[3] Second, unlike other studies done at national and regional levels that mostly focus on biophysical outcomes, energy, and infrastructure separately (e.g., Chinowsky et al. 2015; Fant et al. 2015; Fant et al. 2015; Schlosser and Strzepek, 2015), we combine biophysical assessments with an economy-wide dynamic computable general model based on the 2007 Social Accounting Matrix (SAM) for Zambia. This allows us to give a more nuanced subnational level analysis of the socio-economic impacts of climate change on a range of economic outcomes including economic growth, agriculture share in GDP, and household welfare.

Specifically, we attempt to address five interrelated questions: (i) what are the potential impacts of climate change on crop yields in Zambia and what does this mean for existing national agriculture policy? (ii) what are the potential impacts of climate change on agriculture production at subnational level?[4] (iii) what are the implications of climate change for economic development? (iv) what are the impacts of climate change on household welfare at subnational level? And, lastly, (v) what do the impacts of climate change on agriculture and household welfare imply for adaptation in Zambia?

The rest of the paper is organized as follows. Section 2 gives a brief review of Zambia's agriculture sector and briefly reviews literature on the impacts of climate change on agriculture. We describe the methods and provide brief details on the biophysical, crop and economic models used in Section 3. The results answering the main research questions are then presented in Section 4 followed by a discussion of the main results in Section 5. The paper concludes in Section 6 and draws implications for adaptation policy in Zambia.

2 Overview of Zambia's agricultural sector and impacts of climate change on agriculture

The agricultural sector remains important in Zambia and contributes about 6% to national GDP (World Bank, 2019). The sector provides about 22.3% of employment opportunities in the country, with 4.3% in the formal sector and 18% in the informal sector (ZamStats, 2019).[5] Smallholder farmers dominate the sector and production is largely maize-centric and rainfed

[2] 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).

[3] Crops and groupings include root crops (cassava), other cereals (millet, sorghum, rice, etc.), tobacco, cotton, and maize.

[4] Subnational regions are not necessarily equal to provinces in some instances, these include Central (Central, Lusaka and Copperbelt Provinces), Eastern Province, Northern (Northern, Muchinga and Luapula Provinces), Southern Province, and Western (Western and Northwestern Provinces).

[5] 19.2% of those employed in the agricultural sector are formally employed and 80.8% informally employed.

(Libanda et al. 2016). This production system has left the country, particularly rural smallholders, vulnerable to climate variability and change.

Climate change impacts agriculture through increased frequencies of extreme climatic events such as droughts and floods that directly affect agricultural productivity and production (Jain, 2007; Thurlow et al. 2012). Because climate change is uncertain, it is difficult for farmers to plan their production activities, especially in rainfed farming systems (De Pinto et al. 2019, b). 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 differ by regions. For example, climate change has been found to reduce yields for staple crops such as maize and wheat in lower-altitude regions, while there are yield gains for sugar beets, maize, and wheat in higher altitude and elevation areas (IPCC, 2014; IPCC, 2019).[6]

Like other countries in the region, Zambia has been affected by climate change. Climate change and variability have led to crop failure, livelihood losses, increased incidents of food insecurity, and a reduced contribution of agriculture to GDP in the country (Alfani et al. 2019; Chisanga et al. 2017; Chisanga et al. 2018; Mulenga et al. 2019). The southern parts of the country are projected to be more affected by climate change than are the northern parts and on average, rainfall is expected to be more variable, and rainy seasons are likely to shift (Hamududu and Ngoma, 2019; Mulenga et al. 2017). This makes Zambian agriculture vulnerable to climate shocks, and this is exacerbated by the fact that more than 90% of smallholder production is rainfed (GRZ, 2016a; GRZ, 2016b). Other implications of climate change in the country include electricity rationing of up to 15 h per day and high volatility in maize and maize meal prices due to supply shortfalls and limited irrigation (Mulenga et al. 2019; Chisanga et al. 2018; Ngoma et al. 2017).

Climate change has implications on food security. Frequent extreme climate events are making it difficult to achieve food security and eliminate hunger (von Grebmer et al. 2019). Most of the people expected to fall back into poverty as a direct result of climate change are expected to be the marginalized who live in the driest and the wettest parts in SSA (Azzarri and Signorelli, 2020; Olsson et al. 2014). For Zambia, climate change is expected to negatively affect food security and nutrition because of high poverty levels and low diversification in food production (Verhage et al. 2018; Alfani et al. 2019). Currently, about 63% of energy requirements in Zambia are from cereals and yet cereals like maize—the staple food—are vulnerable to climate change. Thus, it is important to better understand the extent and magnitudes of the impacts of climate change on agriculture to inform adaptation planning in the country.

3 Data and methods

The general framework employed in this research is the Systematic Assessment of Climate Resilient Development (SACRED) framework. This is a chain of modeling analytic tools that look at changes in global systems from the climate system through local economic systems. The modeling framework combines climate science, biophysical, and economic modeling (Arndt et al. 2014). The global climate model explicitly captures all the earth and climate

[6] Higher altitude and elevation areas (e.g., North America, Europe, Arctic), some of which had permafrost which has since melted and opened arable land due to higher temperatures.

science dynamics on a global scale (Sokolov et al. 2005). At the climate science level, the framework uses 17 general circulation models (GCMs), also used in the IPCC's fourth assessment report (AR4). Outputs of this global model are fed into other biophysical models which in turn are fed into an economic model. 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 analysis sets out with 6800 future climate projections and two GHG emissions policies. One policy scenario termed unconstrained emissions (UCE) assumes that there are no successful global efforts to mitigate greenhouse gas (GHG) emissions, while a second scenario dubbed level one stabilization (L1S) assumes that there are successful global efforts to mitigate climate change and limit GHG emissions to less than 560 ppm CO_2 equivalent (Webster et al. 2012 and Fant et al. 2015). The GCMs used in the analysis are based on the Coupled Model Inter-comparison Project (CMIP-3), and the MIT IGSM was used to generate temperature and rainfall projections to 2050. The main outcomes of the GCM modeling are future climates (e.g., temperature and rainfall). Further details on the climate science modeling are given in Schlosser and Strzepek (2015). The 6800 future climate scenarios were reduced to 398 for the L1S and 421 for the UCE scenarios using the Gaussian quadrature approach (see Arndt et al. 2014) for details.

As explained in Fant et al. (2015), several biophysical models were used to link future climates from GCMs to biophysical outcomes. The *ClimCrop* model was used to simulate the impacts of climate change on crop yield, while the *ClimRun* model estimates the impacts of climate change on runoff within catchments defined by future climate inputs and soil characteristics. The Water Evaluation and Planning Model (WEAP) uses the runoff and irrigation parameters from the first two models to allocate water use by priority and the *ClimRoad* model evaluates the impacts of climate change on road networks (infrastructure). Further details on the biophysical these models are given in Fant et al. (2015). In this study, we focused on five different crops, namely, maize, other cereals (wheat, barley, rice, etc.), root crops (such as cassava and potatoes), and the non-traditional crops, cotton and tobacco.

The economy-wide results are derived from a dynamic computable general equilibrium (CGE) model for Zambia. The CGE model is calibrated using a 2007 SAM for Zambia, which has 33 activities and commodities and five regions. This SAM is based on the national SAM by Chikuba et al. (2013).[7] Table 1 provides a summary of the economic structure as reported in the SAM. In 2007, agriculture accounted for 20% of total value added in Zambia and contributed up to 17% of the total wage bill. Services, specifically trade and government sub-sectors, is the largest contributor to gross value added (GVA) and the wage bill. Crops dominate agriculture GVA and wage bill and account for the bulk of exports from the sector. Exports are dominated by mining, while imports are dominated by manufactured goods. The CGE model used assumes that labor can move freely between regions and sectors. Labor 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.

[7] To enable a detailed regional analysis, the SAM developed by Chikuba et al. (2013) was adapted to include a regional dimension for production, land and livestock capital, and households. For ease of modeling, the number of sectors was reduced from 44 to 33 by aggregating some sectors. Electricity production was disaggregated into hydro power and diesel to enable the analysis of climate change on power production. See Table S2 for the 2007 SAM accounts and commodities.

Table 1 Structure of the national economy of Zambia, 2007

	Share of total (%)				Exports/output (%)	Imports/demand (%)
	GVA	Wage bill	Exports	Imports		
All sectors	**100.0**	**100.0**	**100.0**	**100.0**	**18.2**	**13.4**
Agriculture	20.03	16.71	6.05	1.36	4.92	1.42
Crops	11.23	5.02	5.41	0.87	8.62	1.78
Livestock	2.56	3.81	0.64	0.49	3.50	3.41
Forestry	4.84	5.78	–	–	–	–
Fishing	1.40	2.10	–	–	–	–
Industry	29.82	21.92	84.76	78.84	25.34	29.81
Mining	4.90	2.04	73.73	4.13	98.23	75.79
Manufacturing	9.70	6.11	6.46	70.27	4.10	38.09
Other industry	15.22	13.77	4.57	4.44	4.86	4.73
Services	50.17	61.34	9.21	19.81	3.33	6.91
Trade	24.79	31.87	6.28	–	4.42	–
Transport	4.83	4.26	2.93	16.73	10.27	39.58
Finance & business	9.73	8.58	–	3.08	–	5.09
Government	10.17	15.90	–	–	–	–
Other	0.65	0.73	–	–	–	–

Source: 2007 SAM

Notes: GVA is gross value added; wage bill refers to the factor return to labor. Exports/output (%) reports the share of exports in total sector output, and imports/demand (%) reports the share of imports to total commodity demand. Other industry includes construction, electricity, and water sub-sectors

The CGE model includes outputs from the biophysical models as inputs to estimate the economic impacts of climate change. SAMs and CGE models provide a full picture of flows in the economy and the advantage of using these in climate analysis is that they allow a simultaneous assessment of the direct, indirect, and induced impacts of climate change on the economy in a consistent manner. This modeling framework further enables the assessment of several key indicators used by decision makers and can, therefore, help form an evidence base for policy decisions. The framework also helps to better study the impacts of climate change and to identify the most vulnerable groups. Readers are referred to Arndt et al. (2014) for details on the CGE framework. The models include sub-regions (covering one or more provinces) and provide a nuanced picture of the biophysical and economic impacts of climate change in Zambia. Even though we have results for the entire study period (2011 to 2050), we focused on average impacts over the last 5 years (2046 and 2050) to avoid intra-annual variation which can be present in single year results and such that the full impact of climate change over the period is analyzed.

Climate impacts are measured as the difference between the baseline scenario and outcomes under UCE and L1S scenarios, respectively. The baseline scenario is a business-as-usual scenario for the economy and includes historical climate trends (see Fant et al. 2015, for details). The impacts of climate change on the local economy as well as adaptation and mitigation policies and measures are not included in the baseline scenario, although resulting world price changes from climate change are considered. The growth trajectory for the baseline scenario averages 4.9% over the period, which is aligned to historical growth which averaged 4.9% over the 2010–2019 period (World Bank Data Bank).[8] The sector contribution

[8] https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2019&locations=ZM&start=2010 (accessed 21 June 2021)

remains relatively unchanged over the period, although the share of agriculture to GDP does decline and the share of industry increases. Table 2 below presents the average growth rate by decade. National land and livestock supply are assumed to growth by 0.5% per annum over the period. Tertiary, secondary, primary, and no-school laborers are assumed to grow by 3%, 2.4%, 1.9%, and 1.7% per annum, respectively. The shift of resources in the economy under climate change help to identify where adaptation resources may be more effectively applied (Fant et al. 2015).

Tables 1 and 2 show two things. First, even though the contribution of agriculture to GDP has declined a lot since the baseline scenario from about 20 to about 6%, the structure of the economy remains largely the same. The service sector still dominates, mining still dominates exports, and crops are the largest subsector in agriculture. Second, the growth rates used in the baseline scenarios are very comparable to realized averages over the historical period between 2010 and 2019. When considered together, the assumptions in the baseline were not unrealistic but some changes in the structure of the economy support our calls (later in the paper) to update the analysis with a more recent SAM that better captures newer relationships in the economy.

4 Results

We present selected results from the crop, biophysical and economy-wide modeling the UCE scenario. We will only refer to results of the L1S scenario when making critical comparisons. We will focus only on subnational or regional results for Zambia.[9] Although climate change can affect outcomes through different channels, we restrict our analysis to the agriculture channel. Tembo et al. (2020) report compounded results from the agricultural, energy, and infrastructure impact channels. We first present results of projected changes in temperature and rainfall before moving on to present biophysical and economic results. Unless, otherwise stated, we present the biophysical and economy-wide results at the regional/subnational levels for Zambia.

4.1 Projected changes in rainfall

At the regional level, the Southern and Western regions have the most substantial reductions in rainfall averaging between 3 and 4 percentage points with an interquartile range of 8 (Figs. 1 and S1). This suggests that the Southern and Western regions of Zambia are the most vulnerable to climate change and will likely experience more reduced rainfall over time and in the worst-case scenario, rainfall may reduce by 20–30 percentages points in these regions. On the contrary, the Northern region is projected to receive nearly 5 percentage points more rainfall by 2050. The right panel of Fig. 1 and Table S1 give more detailed graphics and summary statistics for changes attributable to climate change at regional level.

[9] As stated before, the five regions include central, northern, eastern, southern, and western parts of Zambia. These are broadly defined here and each one may include several provinces.

Table 2 Historical and baseline scenario growth by broad sector

	Agriculture	Industry	Services
Historical			
2010–2019	−0.5%	3.9%	6.4%
CGE model			
Decade 1 (2011–2020)	4.1%	4.6%	4.5%
Decade 2 (2021–2030)	4.5%	5.0%	4.9%
Decade 3 (2031–2040)	4.9%	5.2%	5.2%
Decade 4 (2041–2050)	5.4%	5.3%	5.3%

Source: Historical data is from the World Bank Data Bank; decadal growth rates are from the CGE model for Zambia

4.2 Projected changes in temperature

Temperature is projected to be around 1.8 °C higher by 2046–2050 across all regions under the UCE scenario, although temperature increases could be as large as 3.6 °C (Fig. 2 and Table S1). Notably, all regions are expected to experience temperature increases of above the often used 1.5 °C threshold (Fig. 2, right panel).[10]

4.3 Impacts of climate change on crop yields

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. According to the 2007 SAM for Zambia, the focal crops—maize, cotton, tobacco, root crops, and other cereals—account for just over 70% of the total agricultural crop production in Zambia (Chikuba et al. 2013). We report the mean, median, minimum, and maximum values and the interquartile range for yield deviations of these crops in Table 3 and highlight several key findings.

First, on average, climate change is likely to reduce the yields for maize, other cereals, root crops, and tobacco up to the end of the study period with appreciable differences in the impacts of climate change on these crops by 2050. Second, maize is projected to be the worst affected crop, with estimated yield reductions of up to 3–6 percentage points and an interquartile range of between 7 and 8.5 in the worst affected Southern and Western regions under the UCE scenario. In these regions, yield variability is high, ranging from − 30 to 26 percentage points. However, maize productivity is likely to be less affected (< 2 percentage points) by climate change in the Central, Eastern, and Northern regions of Zambia, which account for 50–60% of total maize production (Chikuba et al. 2013; CSO/MAL/IAPRI 2019).

Third, cotton and root crops are projected to be less adversely affected by climate change. Cotton yields increase by 1 percentage point in the Northern regions of Zambia by 2050, while root crop yields rise by 0.50 percentage points. The range of outcomes are however broad (Table 3).

[10] The 1.5 °C threshold was discussed in the 2018 IPCC Special Report which warns that an increase in temperature of 1.5 °C above the pre-industrial levels will result in significant risks to food security, livelihoods, and economic development.

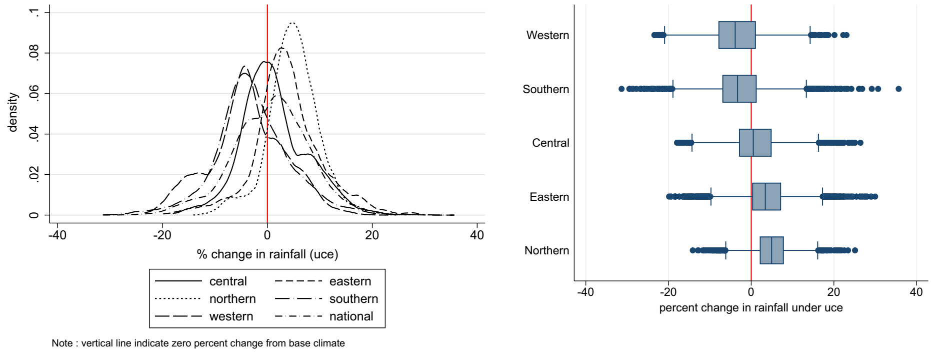

Fig. 1 Regional percent change in rainfall under unconstrained emissions showing density plots (left panel) and box plots with interquartile range (right panel), 2046–2050. *Notes: Zero line shows zero deviation between outcomes with and without climate change. Source: Authors*

It is difficult to read too much into the results for other cereals because this category includes several crops such as wheat, barley, and rice. As such, it is difficult to isolate the impacts of climate change on any one of the constituent crops. 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 regions.

The largest negative yield impacts are expected to take place in the Southern and Western regions of the country which account for roughly 26% of agriculture value added. Here, large uncertainties in the level of impact are also highlighted—see differences between the minimum and maximum values and the interquartile range in Table 3.

We graphically show the regional differences in the impacts of climate change on crop productivity using maize and cotton in Fig. 3. With this presentation, it becomes clearer that Southern and Western regions are most affected.

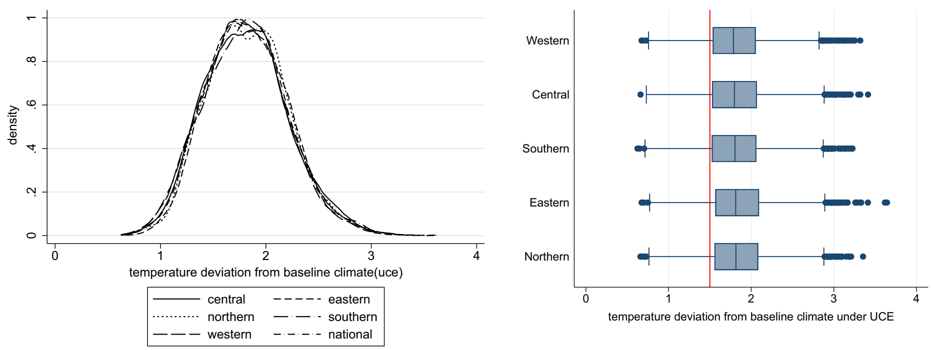

Fig. 2 Regional deviations in temperature (°C) under unconstrained emissions showing density plots (left panel) and box plots with interquartile range (right panel, 2046–2050. *Notes: The red vertical line is on 1.5 °C. Source: Authors*

Table 3 Regional percentage point change in crop yield growth under unconstrained emissions, ratio relative to no change, 2046–2050

	Minimum	Maximum	Mean	Median	Interquartile range
Maize yield					
Central	−16.23	18.20	−1.39	−1.81	5.38
Eastern	−13.30	17.92	−0.07	−0.07	4.80
Northern	−9.99	7.93	−0.63	−0.41	3.35
Southern	−21.89	25.98	−3.39	−4.36	7.18
Western	−30.52	16.91	−6.40	−5.90	8.45
Cotton yield					
Central	−5.60	5.54	−0.47	−0.44	1.93
Eastern	−4.43	4.97	−0.20	−0.09	1.48
Northern	−3.46	4.57	1.29	1.38	1.53
Southern	−7.53	3.03	−1.62	−1.54	2.14
Western	−5.51	3.67	−1.25	−1.31	2.49
Other cereal yield					
Central	−8.30	6.62	−1.78	−1.84	2.23
Eastern	−6.93	5.34	−0.95	−0.90	2.03
Northern	−4.91	2.61	−1.18	−1.18	1.39
Southern	−11.01	11.47	−2.11	−2.39	3.28
Western	−13.13	7.49	−3.31	−3.13	4.03
Root crop yield					
Central	−11.03	11.32	−1.49	−1.74	3.63
Eastern	−13.77	16.05	−3.17	−3.50	4.40
Northern	−9.44	5.71	0.44	0.50	1.81
Southern	−16.31	9.19	−4.38	−4.30	3.83
Western	−18.78	11.18	−3.65	−3.68	4.80
Tobacco Yield					
Central	−7.37	7.27	−1.88	−2.14	2.03
Eastern	−7.70	11.78	−1.34	−1.47	1.93
Northern	−6.15	3.81	−1.13	−1.17	1.51
Southern	−20.97	6.89	−3.67	−3.43	3.64
Western	−21.97	6.95	−4.44	−3.61	4.22

Source: Authors

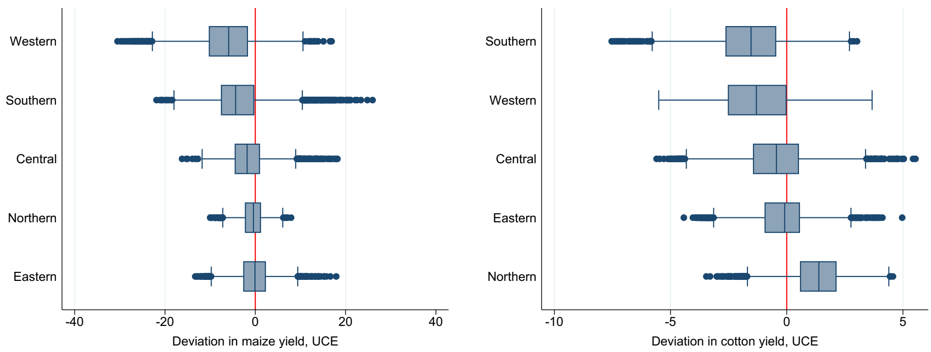

Fig. 3 Regional impacts of climate change on maize productivity (left panel) and cotton productivity (right panel) under unconstrained emissions, ratio relative to no change, 2046 to −2050. *Notes: Zero line shows zero deviation between outcomes with and without climate chang*e. Source: Authors.

Table 4 Regional impacts of climate change on production by crop under unconstrained emissions—ratio relative to no change, 2046–2050

	Minimum	Maximum	Mean	Median	Interquartile range
Maize production					
Central	0.89	1.11	0.99	0.98	0.05
Eastern	0.92	1.12	1.01	1.01	0.05
Northern	0.91	1.07	1.00	1.01	0.03
Southern	0.80	1.22	0.96	0.94	0.10
Western	0.61	1.15	0.91	0.92	0.11
Other cereal production					
Central	0.93	1.08	0.99	0.99	0.03
Eastern	0.96	1.09	1.02	1.01	0.04
Northern	0.96	1.04	1.01	1.01	0.02
Southern	0.90	1.13	0.98	0.97	0.06
Western	0.79	1.08	0.96	0.96	0.06
Root crop production					
Central	0.88	1.10	0.97	0.96	0.05
Eastern	0.79	1.18	0.92	0.91	0.07
Northern	0.96	1.04	1.01	1.01	0.01
Southern	0.75	1.09	0.89	0.90	0.07
Western	0.79	1.11	0.93	0.92	0.07
Tobacco production					
Central	0.95	1.08	0.99	0.99	0.02
Eastern	0.94	1.10	1.00	1.00	0.02
Northern	0.96	1.08	1.01	1.01	0.02
Southern	0.80	1.09	0.96	0.96	0.04
Western	0.74	1.07	0.95	0.96	0.06
Cotton production					
Central	0.95	1.06	1.00	1.00	0.02
Eastern	0.98	1.04	1.00	1.00	0.01
Southern	0.93	1.02	0.97	0.97	0.02

Source: Authors

4.4 Impacts of climate change on agricultural production

Table 4 presents results on the impacts of climate change on production for specific crops and by region. These results highlight two main nuances. These impacts are measured as the ratio relative to the baseline scenario. As such, a value >1 implies an increase relative to the baseline scenario without climate change, and a value of <1 implies the converse.[11] First, among the five crops considered, climate change is projected to reduce maize production much more than for any other crop by 2050 under UCE. Cotton production is least affected by climate change, with no noticeable changes in Central and Eastern regions. 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 min and max values for each region and the interquartile range in Table 4. Therefore, production resources will likely shift out of the Southern and Western regions, where possible, and into the Northern, Eastern, and Central regions. When adding in the other impact channels,

[11] Similar logic applies for GDP and household expenditure.

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.

Figure 4 shows these regional differences in the impacts of climate change on maize production and root crops.

4.5 Impacts of climate change on gross domestic product (GDP)

The impacts of climate change on the general economy by decade under UCE are presented in Fig. 5. While climate change is projected to reduce GDP throughout the 4 decades, the negative impacts are progressive with time as is the uncertainty of these impacts (Fig. 5). For example, the impact of climate change on GDP in the first decade deviates only by a smaller margin from unity when compared to the fourth decade. Thus, climate change is expected to progressively reduce GDP over time in Zambia. Readers are referred to Tembo et al. (2020) for more details on the cumulative impacts of climate change on the economy.

4.6 Impacts of climate change on total household welfare

We use household expenditure as a measure of household welfare. Figure 6 presents results by region and expenditure quintiles for rural households. The main finding is that climate change is projected to have larger negative effects on household expenditure for rural households in Southern and Western regions across all quintiles during the 2046–2050 period. The effects of climate change on expenditure do not seem to differ much by quintiles among rural households.

4.7 UCE versus L1S

The foregoing results show the potential impacts of climate change on the Zambian economy under the UCE scenario. When compared to results under the L1S scenario, the UCE scenario paints a more negative picture for Zambia with higher levels of uncertainty (see Fig. 7). For example, the impacts of climate change on maize production are less uncertain under the L1S scenario relative to UCE. This can be seen in wider confidence intervals under UCE (Fig. 7, left panel) compared to L1S (Fig. 7, right panel). This is the case generally across all crops and

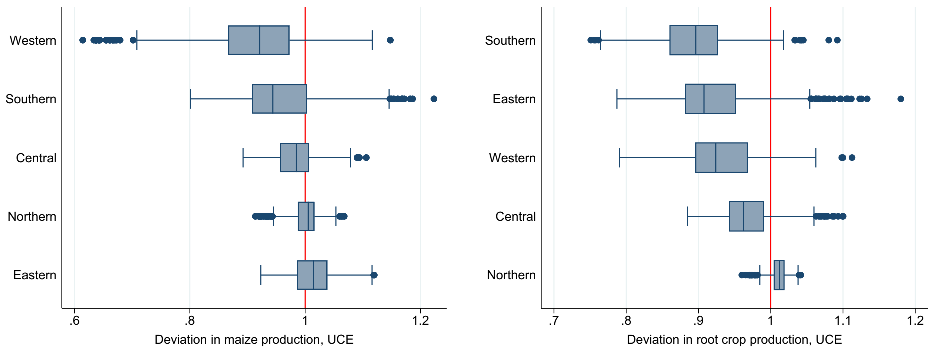

Fig. 4 Regional impacts of climate change on maize production (left panel) and root crop production (right panel) under unconstrained emissions—ratio relative to no change, 2046–2050. *Notes: Unit line shows no deviation between outcomes with and without climate change. Source: Authors*

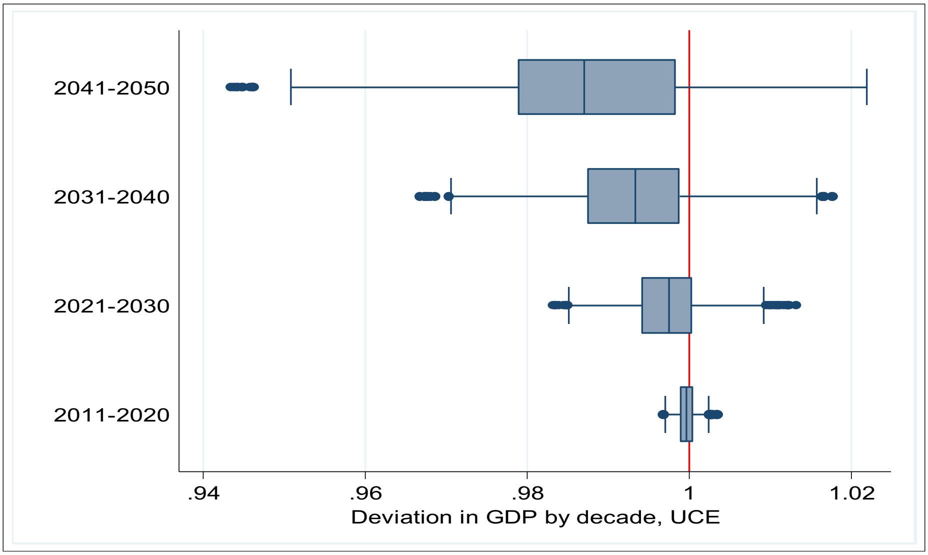

Fig. 5 Decadal impacts of climate change on national gross domestic product under unconstrained emissions—ratio relative to no change, 2046–2050. *Notes: Unit line shows no deviation between outcomes with and without climate change. Source: Authors*

regions because there is less uncertainty in temperature, precipitation, and evaporation changes under L1S. These differential results suggest that there is value in taking climate action now to minimize the likely future negative effects of climate change.

5 Discussion

5.1 Impacts of climate change on crop yields and production

Our results projecting hotter temperatures and reduced rainfall by 2050, and negative effects of climate change on crop productivity and production for Zambia are aligned with the findings of Thurlow et al. (2012) and Hamududu and Ngoma (2019). The progressive nature of the negative effects of climate change in this paper is in line with Arndt et al. (2014) who similarly found that the effects of climate change become more negative and begin to impede overall prospects of economic growth between the 2030s and 2040s. In line with other studies (e.g., IPCC, 2019; Verhage et al. 2018; GRZ, 2016a; Mulenga et al. 2015), maize is the most vulnerable crop to climate change in Zambia.

These findings have implications for national food security and agricultural incomes. This is because cereal crops (wheat and maize) are a staple food and provide 63% of the energy requirements in Zambia (Mwanamwenge and Harris, 2017; Chapoto and Sitko, 2015). The lower yield reductions for cotton, other cereals, root crops, and tobacco point to the need to diversify production away from maize to lessen the risks of climate-induced crop failure and food insecurity in Zambia.[12] In this regard, there is need for adaptation measures that can help

[12] However, changing crop production patterns may be faced with the need to change consumption patterns. Whether diets can be changed that easily in Zambia is an empirical question.

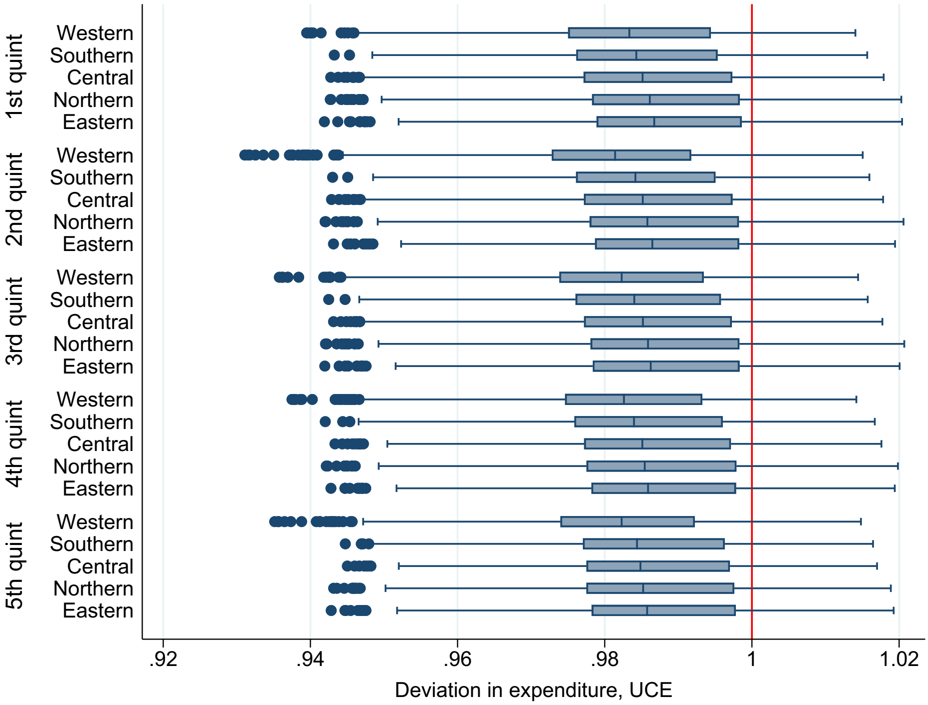

Fig. 6 Impacts of climate change on total real household expenditure under unconstrained emissions by region and expenditure quintile for rural households—ratio relative to no change, 2046–2050. *Notes: Unit line shows no deviation between outcomes with and without climate change. 1st quint–5th quint captures the first quintile (0–20%) up to the fifth quintile (80–100%).Source: Authors*

farmers cope and adapt to climate change and variability. Such measures might include investments in efficient and cost-effective small-scale irrigation and scaling-up adoption of region-specific drought and heat tolerant crop varieties. Other options include nudging and scaling out sustainable adoption of sustainable agricultural technologies and practices, promoting diversified agricultural production, investments in R&D, market development, extension systems, and market-driven production support/incentive systems for alternative crops that are suitable in the specific regions of Zambia.

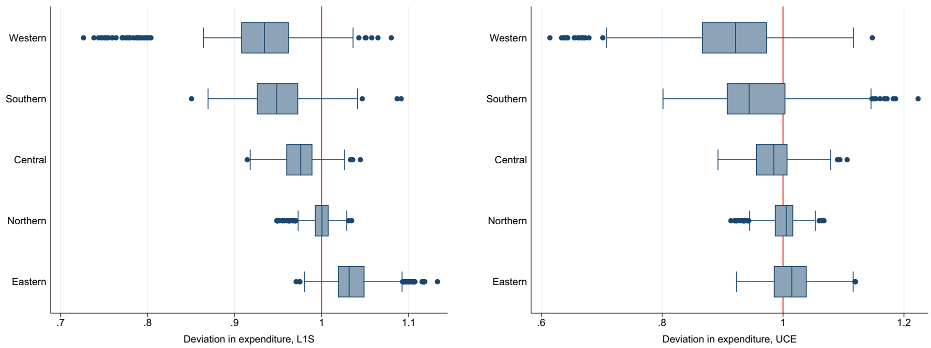

Fig. 7 Regional impacts of climate change on maize production under unconstrained emission scenario (left panel) and level one stabilization (right panel)—ratio relative to no change, 2046–2050

The regional differences highlighted in this paper raise concerns because southern and western regions are important maize-producing areas in Zambia. These two regions accounted for 30% of the national maize output during the 2017/2018 farming season (CSO/MAL/IAPRI, 2019). This regional aggregation, however, masks the importance of individual provinces which shows that with 19% of the total maize output, Southern Province was the highest maize producer during the 2017/2018 season in Zambia. As such, the projected more negative effects of climate change on southern and western regions have important implications for agricultural development and food security in Zambia. Thus, the combined negative impact of climate change on crop production in the Southern and Western regions is the key driver of the decline in total agriculture value added. Regarding 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.

Although our results seem to corroborate existing studies (Thurlow et al. 2012; Hamududu and Ngoma, 2019), the subnational level results are additional. This is because subnational level results help identify regions most likely to be negatively affected by climate change. Although we do not directly account for adaptation in the analysis, subnational results can help policy to target adaptation interventions in these areas that are most likely to be affected by climate change. The differential results by crop and region can further help refine targeting in this regard.

5.2 Impacts of climate change on economic development and household welfare

The negative effects of climate change on total GDP and household welfare are in line with prior work in Southern Africa (see Arndt et al. (2011), Arndt et al. (2012), Arndt et al. (2014), and Cullis et al. (2015)). Like in the current study, these studies find that climate change is expected to negatively affect economic growth and development, especially without global mitigation. Our findings are also in line with Thurlow et al. (2012) who suggest that climate change will reduce GDP and increase the poverty incidence in Zambia. That climate change is likely to reduce expenditure for rural households in the vulnerable Southern and Western regions of Zambia point to a potential link between climate change and poverty.

In sum, the negative effects of climate change on Zambia agriculture, economic growth, and household welfare found in this paper corroborate and add to prior studies by showing the differential impacts of climate change at regional level. These findings have important implications for poverty alleviation and economic development in the country and for adaptation planning and targeting. These findings raise policy concerns given the importance of the agricultural sector in Zambia. To address the situation, the Zambia government has prioritized climate mitigation and adaptation through national policies such as the Second National Agricultural Policy and the National Policy on Climate Change and the Nationally Determined Contributions to the 2015 Paris Climate Agreement. However, more needs to be done to raise finances to support these efforts and to ensure that effective mitigation and adaptation actions are sustainably adopted and utilized by smallholder farmers in the country.

Readers should bear in mind that our results are lower bound estimates because they are only based on the agricultural impact channel. The state of infrastructure such as roads matters for market access and trade, while the energy sector is critical as an engine for growth. Thus, any negative impacts of climate change on road infrastructure are likely to exacerbate food insecurity by either disrupting supply chains, raising transaction costs, or both. Production is directly affected by any negative effects of climate change on energy. Thus, the cumulative impacts of climate change via agriculture, infrastructure, and energy are expected to be larger as demonstrated in Tembo et al. (2020). Future research is required to directly account for adaptation/mitigation costs in assessing the impacts of climate change on agriculture and economic development.

6 Conclusion

While it is understood that climate change negatively affects agriculture and livelihoods in agrarian countries like Zambia and that these effects are progressive with time, it is less certain what the magnitudes are, how the impacts differ by crop and at subnational level. The uncertainty associated with climate change adds another layer of unknowns. Yet, such an understanding is crucial to inform adaptation plans as articulated in national policies. This paper contributes towards filling this knowledge gap. We draw on a modeling framework of Arndt et al. (2014) that combines climate, biophysical, and economy-wide models to assess the impacts of climate change on agriculture and household welfare. We address the uncertainty associated with climate change by analyzing the impacts of a large set of potential future climates. Unlike other similar studies, this integrated framework allows us to combine biophysical and economy wide modeling, covering the whole gamut from climate science to economic outcomes and allows us to show results at both national and subnational levels.

There are three main findings: first, rainfall is projected to reduce by between 3 and 4 percentage points (median values) in the worst affected Southern and Western regions of Zambia by mid-century in 2050. Over the same period, temperature is projected to increase by about 1.82 °C. Second, the changes in rainfall and temperature will likely lead to progressive declines in crop yield and production, with maize expected to be the hardest hit, especially in the Southern and Western regions. And, lastly, based only on the agricultural impact channel, climate change will likely reduce the national GDP and household expenditure. The Southern and Western regions are projected to have the most substantial negative impacts of climate change on crop yield and production, and will become progressively more vulnerable over time. We therefore conclude that climate change and variability (e.g., reduced rainfall and higher temperatures) will negatively affect agricultural productivity and production, economic development, and livelihoods. And that the impacts of climate change are unevenly spread, likely weighing more heavily in the Southern and Western regions of Zambia, and are likely to be progressive with time.

We draw three main implications from the findings in this paper. First, although we do not directly account for adaptation in the analysis, subnational results in this study can help policy to target adaptation interventions in areas that are most likely to be affected by climate change. The differential results by crop and region can further help refine targeting in this regard. The projected increases in temperature and reductions in rainfall imply that it may become very challenging for smallholder farmers in Zambia to rely on rainfed production systems without significant adaptation. Thus, there is an urgent need to invest in efficient and cost-effective small-scale irrigation and scaling-up adoption of region-specific drought and heat-tolerant crop varieties to enable smallholders to adapt to climate change in Zambia. Financing and nudging sustainable adoption of sustainable agricultural technologies and practices should be key elements of adaptation planning. Second, that maize—the national staple crop—is projected to be the worst affected crop by climate change reinforces the need for diversified production. This will require investments in R&D, market development, extension services and market-driven production support/incentive systems for alternative crops that are suitable in the specific regions of Zambia. And lastly, the progressive and cumulative nature of the expected impacts and, on average, the lower impacts under the scenario with mitigation present rays of opportunities to act now to reduce the projected negative impacts of climate change.

While this analysis considered the impacts of long-term changes in climate on the economy of Zambia, it did not consider the impact of short-term changes in weather which includes the impacts of droughts and floods. This is an important area of future research. The Systematic Assessment of Climate Resilient Development (SACRED) framework also only considers the economic impact of the climate channels outlined. Additional climate impact channels exist, including impacts through biodiversity channels. Adding these channels and improving on the types of models used in existing channels could add value to the climate change literature. Factoring in the impacts of mitigation actions in global scenarios would add value to future analysis. As the economic analysis in this paper is based on a 2007 SAM, there is scope to update this analysis with a more recent SAM to better capture newer relationships in the economy such as the notable decline in the contribution of agriculture to national gross domestic product.

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Authors' contributions Ngoma and Hartley conceptualized and performed parts of the analysis and wrote the first draft; Hartley re-run the CGE models as needed; Lupiya conducted parts of the analysis; while Kabisa contributed to writing and reviewing the paper. The distribution of tasks was evenly shared.

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Data availability Data used in this research is available from the funders.

Code Availability Codes used on the analysis are available from the authors.

Declarations

Conflicts of interest The authors declare no conflict of interest.

Disclaimer The contents are the responsibility of the authors and do not necessarily reflect the views of USAID, the United States Government, SIDA, IFPRI, SA-TIED or IAPRI.

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