Working Paper Series

The KENYA INSTITUTE for PUBLIC POLICY RESEARCH and ANALYSIS

ECA

Climate Change, Agricultural Production, Trade, Food Security and Welfare in East African Community

Nancy Laibuni
John Nyangena
Augustus Muluvi
Christopher Onyango

WP/31/2019

THE KENYA INSTITUTE FOR PUBLIC POLICY RESEARCH AND ANALYSIS (KIPPRA)

AND

UNITED NATIONS ECONOMIC COMMISSION FOR AFRICA (UNECA)

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KIPPRA Working Paper No. 31
2019

The KENYA INSTITUTE for PUBLIC POLICY RESEARCH and ANALYSIS

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Published 2019

Bishops Garden Towers, Bishops Road
PO Box 56445-00200 Nairobi, Kenya
tel: +254 20 2719933/4; fax: +254 20 2719951
email: admin@kippra.or.ke
website: http://www.kippra.org

ISBN 9966 817 13 6

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This paper has been published under the KIPPRA/UNECA Project on Regional Assessment of Agricultural Production, Climate Change, Agricultural Trade and Food Security in the East African Community.

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Foreword

Climate change and climate change variability is a threat to food production patterns, thus exacerbating food and nutrition insecurity across Africa. Therefore, tackling poverty, hunger and food security is a priority for the Africa Union Agenda 2063, which underscores the right of Africans to live healthy and productive lives. Further, the African Union has set a target to eliminate hunger and food insecurity by 2025 towards achieving the Sustainable Development Goal (SDG) 2 on ending hunger, achieving food security and improving nutrition. Unfortunately, Africa is not on track in meeting these targets, mainly because the region is not producing enough food due to climate change and low adoption of technology. However, climate change has variable impacts on food production, with both production losses and gains across the region. As a result, regional trade is critical for facilitating the distribution of agricultural products to enhance food security in the region.

The East Africa Community (EAC) region is particularly vulnerable to climate change. The region is already experiencing increased climate change impacts, including extreme weather conditions, persistent drought, foods, and landslides and rising sea level, which threaten food security and efforts to eradicate poverty. Despite the huge potential to produce enough food, the agricultural production system in the region is mainly rainfed, which consequently leads to high food and nutrition insecurity. Finding solutions to perennial food security challenges in the EAC is crucial and urgent as climate change impacts intensify in frequency and severity. Looking beyond just agricultural production systems is thus critical in tackling this peril. Thus, there is need to apply other approaches such as the nexus approach, which allows for evaluating integrative systems where, for instance, trade facilitates food security in a changing climate environment. Although agriculture production is vulnerable to climate change, food security is not necessarily a result of low production but a combination of other factors such as poor food distribution caused by perverse subsidies and other trade barriers.

The EAC has been able to attain a common market status, which could facilitate trade in the region and thus mitigate food shortages. Despite the various measures and programmes adopted in EAC, some parts of the region continue to face food deficits due to restrictive trade policies and barriers to trade. Opportunities exist for adopting existing policy frameworks by member countries to address food security needs.

Preface

The project on Regional Assessment of Climate Change, Agricultural Production, Trade in Agricultural Production and Food Security in East African Community (EAC) was carried with support from the ACPC-ClimDev-Africa Work Programme. The ClimDev-Africa Programme is an initiative of the African Union Commission (AUC), the United Nations Economic Commission for Africa (UNECA) and the African Development Bank (AfDB). It is mandated at the highest level by African leaders (AU Summit of Heads of State and Government). The Programme was established to create a solid foundation for Africa's response to climate change and works closely with other African and non-African institutions and partners specialized in climate and development.

Over the last few years, our understanding and certainty about how climate is changing and the possible impacts this could have has grown immensely. This notwithstanding, agricultural production systems in the EAC region are highly vulnerable to climate change, consequently affecting food and nutrition security. The region is the most developed Regional Economic Community (REC) in Africa, and cross border trade plays a critical role in facilitating food security. In response, the United Nations Economic Commission for Africa–African Climate Policy Centre (ACPC) is increasing its efforts to improve the capacity of EAC member states for mainstreaming climate change impacts in development policies, frameworks and plans.

The three-year project was launched in May 2014 covering Burundi, Kenya, Rwanda, Tanzania and Uganda. The activities carried in this study were linked to the ClimDev-Africa Programme work stream II, which focuses on solid policy analysis for decision support, and was spearheaded by the Kenya Institute for Public Policy Research Analysis (KIPPRA). The overall objective of the project was to assess whether or not agricultural production systems and trade policies in EAC can be adjusted to alleviate the impact of climate change on food security and promote sustainable development. The project outputs include pre-project report, country scoping studies, in-depth EAC studies on climate change, crop production model, economic policy and trade and finally a comprehensive regional report.

Acknowledgements

The study was conceptualized and commissioned by the African Climate Policy Centre (ACPC), United Nations Economic Commission for Africa (UNECA), under the leadership of Dr Fatima Denton, Director of the Special Initiative Division, UNECA. Dr Tom Owiyo and Dr Johnson Nkem, Senior Experts at ACPC, guided the conceptual framing and provided oversight during implementation. Regular technical support was provided by ACPC researchers, Dr Wifran Moufouma Okia, Mr Nassirou Ba, Dr Habtamou Adessou, and Research Fellows Yosef Amha and Rivaldo.

The study was conducted as a part of the activities of the Climate Change and Development in Africa (ClimDev-Africa) Programme supported by the UK Department for International Development (DfID), European Union Commission, Norway, Sweden, France, Nordic Development Fund, and the United States Agency for International Development (USAID). The Executive Director of KIPPRA and the Executive Secretary of UNECA would like to acknowledge the KIPPRA technical team comprising Nancy Laibuni (Project Coordinator), Dr Augustus Muluvi, Dr Christopher Onyango, Mr John Nyangena, Mr Simon Githuku, and Mr Nixon Murathi; and the project consultants Dr Richard Mulwa, Dr Miriam Omolo, Dr Wilfred Nyangena, Prof. Caleb Mireri, and Dr Wellington Mulinge. In addition, we appreciate the Eastern and Southern Africa Region Office of the World Metrological Organization, led by Dr Elijah Mukhala and the Consultants, Mr Nicholas Maingi and Dr Joshua Ngaina for their contributions to the project.

The regional partner institutions included Economic Policy Research Centre (EPRC)–Uganda team lead by Dr Isaac Shinyekwa, Sokoine University–Tanzania team led by Prof. Siza Tumbo, University of Burundi team led by Dr Alex Ndayiragije, and Kigali Independent University team led by Mr Paul Muzungu. The participation of the stakeholders in various stages of the preparation of the report was highly valuable in enriching the report. The Economic Commission for Africa and KIPPRA would like to express their appreciation to all the government Ministries, State Departments and Agencies in Burundi, Kenya, Rwanda, Tanzania and Uganda for their active participation and providing the data and information used in preparing the report.

Abbreviations and Acronyms

ACMV	African Cassava Mosaic Virus
AEZ	Agro-Ecological Zones
APSIM	Agricultural Production Systems sIMulator
CIA	Central Investigation Agency
CMIP	Coupled Model Inter-Comparison Project
CORDEX	Coordinated Regional Downscaling Experiment
DfID	Department for International Development
EAC	East Africa Community
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Nino Southern Oscillation
FAO	Food and Agriculture Organization
GCMs	General Circulation Model
IPCC	Inter-governmental Panel on Climate Change
IRI	International Research Institute
RCMs	Regional Circulation Models
SMHI	Sveriges Meteorologiska och Hydrologiska Institut
SRES	Special Report on Emission Scenarios
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

The East African Region is already experiencing increased climate change impacts including extreme weather conditions, persistent drought, floods, and landslides and rising sea level which threaten food security and efforts to eradicate poverty. The dependence on rain-fed agriculture in the region implies that agricultural production will continue to be highly vulnerable to climatic variability and climate change, mainly in form of shifts and changes in rainfall patterns and increasing temperatures leading to adverse impacts to social, physical, ecological and economic systems. The food security situation is further exacerbated by mounting restrictions on cross-border trade on agricultural products in the EAC region.

This report specifically reviews the policies on climate change, agriculture production and trade; explores the spatial effects of climate change on agricultural production; assess the welfare implications of regional agricultural and trade policies and identifies the potential effects of climate change on food security in the region.

The report adopts four models that integrate climate change, food production and security, trade and welfare implications. In the first step, simulations of future climate conditions (temperature, rainfall) from Global Climate Models (GCMs) are spatially downscaled and fed into a crop simulation model which assesses the changes in yields for maize in different agro-ecological zones in the EAC region. Output from the crop simulation model were then fed into the spatial equilibrium model (SEM) that was used to estimate the impacts of agriculture and trade policies on household welfare in the region. Finally, welfare implications are derived from analysis of resulting impacts across various food poverty lines. Projections were carried out for mid-century (2045).

The downscaled climate change models show that rainfall is highly variable in the EAC region both in time and space. In Kenya, Uganda, Rwanda and Tanzania rainfall is showing an increasing trend. However, for Burundi, the trend is highly varied and was either increasing or decreasing. On the other hand, maximum temperatures within the EAC show uniform change with the exception of Kenya which shows a higher change. For minimum temperatures, trends for Kenya were increasing while for the rest of EAC countries, the changes were minimal.

Agriculture is highly sensitive to climatic parameters and hence vulnerable to climate change. The results indicate that modification of flowering and maturity for maize resulted in comparability of actual yields with simulated yields. The analysis indicates variations in maize production over different ecological zones in the EAC region. The projected climate change is expected to increase the gap in maize yield produced in the different zones in EAC resulting into decreased yield per hectare in some zones and an increase in others.

With regard to welfare, the results indicate that an increase in investments in agriculture would lead to welfare gains taking the prevailing levels of the EAC's Common External Tariffs. However, greater levels of protection through higher tariffs would lead to welfare losses. Variations in climatic conditions however show minimal welfare changes which also vary from country to country.

The study makes several recommendations namely; in light of regional disparities in maize production due to climate change, countries should seek to identify their comparative advantages in production of various grains so that they can sell the surplus production and import commodities with deficits. Besides, EAC partner states are encouraged to increase investments in agriculture, especially in research and development in view of mitigation the impacts of climate change.

Finally, removal of trade restrictions i.e. tariff and non-tariff barriers is essential in stimulating increased production and ensuring food security in the region.

1. Introduction

1.1 Background

Climate change poses one of the greatest challenges in the 21st century with far reaching implications on natural and human systems[1]. Africa is particularly vulnerable to climate change impacts due to the interactions of multiple stressors, including extreme poverty, over-dependence on rain-fed agriculture, HIV/AIDS prevalence, insufficient public spending on rural infrastructure, poor data availability and quality, and knowledge gaps (UNEP, 2005; IPCC, 2007). Temperatures in the region have increased by 0.5 degrees Celsius in the last 50 years with the minimum temperatures rising more rapidly than maximum temperatures (Niang, et al. 2014). It is projected that temperatures in Africa will increase faster than the global average; some parts will record reduced rainfall while others will experience enhanced rainfall (IPCC, 2014).

There are fundamental links between climate change, agriculture, trade and food security in Africa. The agricultural production system is vulnerable due to reliance on rainfall, high intra and inter-seasonal weather variability, recurrent drought and floods and the low adoption of technology. Climate change impacts on food production with both production losses and gains across the region. As a result, less restrictions in regional agricultural trade is critical for facilitating distribution of agricultural products to enhance food security in the region.

The IPCC report (2014) predicts that by 2050, crop yields in Sub-Saharan Africa will have declined by 14% (rice), 22% (wheat) and 5% (maize) pushing the vast number of already poor, who depend on agriculture for their livelihoods, deeper into poverty and vulnerability. It also predicts decreased food availability by 500 calories less (a 21% decline) per person and a further increase in the number of malnourished children by over 10 million - a total of 52 million in sub-Saharan Africa (SSA) alone by 2050.

The East Africa Community (EAC) region is characterized by diverse climatic conditions with quick transition from desert to high rainfall areas. Rainfall seasonality is complex and influenced by altitude. The annual cycle of rainfall is bimodal, with wet seasons falling between March to May and October to December. The long rains (March to May) contribute more than 70% to the annual rainfall and the short rains (October to December) less than 20%. Much of the inter-annual variability comes from short rains (the coefficient of variability being 74% compared to 35% for the long rains) (WWF, 2006).

1 Changes to climate that can be identified by changes in the mean and/or the variability of its properties persisting over an extended period of time typically more than 30 years (IPCC, 2007).

The EAC region is already experiencing increased climate change impacts including extreme weather conditions, persistent drought, floods, and landslides and raising sea level which threaten food security and efforts to eradicate poverty (EAC, 2016). These climatic related disasters are usually associated with the climatic variability phenomenon of El Niño Southern Oscillation (ENSO) and poses a major challenge to disaster risk management in the region. Therefore, decreased agricultural production and rampant food insecurity are mainly as a consequence of a changing climate in the region.

The dependence on rain-fed agriculture in the East African Community (EAC) region implies that agricultural production will continue to be highly vulnerable to climatic variability and climate change, mainly in form of shifts and changes in rainfall patterns and increasing temperatures leading to adverse impacts to social, physical, ecological and economic systems (EAC, 2011). The region also suffers from frequent food shortages and hunger despite the region's huge potential and capacity to produce enough food for regional consumption and surplus for export. The main causes of food insecurity in the region are unreliable weather, poor storage, bad roads, market infrastructure, poverty, poor post-harvest management with estimated losses ranging between 30-40%, pests and diseases, use of inappropriate methods and technologies among others (EAC, 2011).

The United Nations Commission for Africa (UNECA) has prioritized the agriculture sector as the major entry point in debates about climate change. In an effort to develop a set of analytical works to understand in more detail about linkages between climate change, agricultural production, trade and food security, UNECA through African Climate Policy Centre (ACPC), commissioned this study covering the EAC region.

1.2 Study objectives

The overall objective of the study was to assess the link between climate change, agricultural production, trade and food security in the EAC region with a view to promote sustainable development. Specific objectives include; (i) Review the policies on climate change, agriculture production and trade, (ii) Explore the spatial effects of climate change on agricultural production, (iii) Asses the welfare implications of regional agricultural and trade policies and (iv) Identify the potential effects of climate change on food security in the EAC region.

1.3 Organization of the report

The rest of the report is organized as follows: chapter two presents methodology, chapter three reviews the policies governing agricultural production, trade and food security while chapter four is on the spatial effects of climate change in agricultural production. The impacts of agriculture and trade policies on household welfare in the region is presented in chapter five. Chapter six and seven presents the synthesis of the report and recommendations and conclusion.

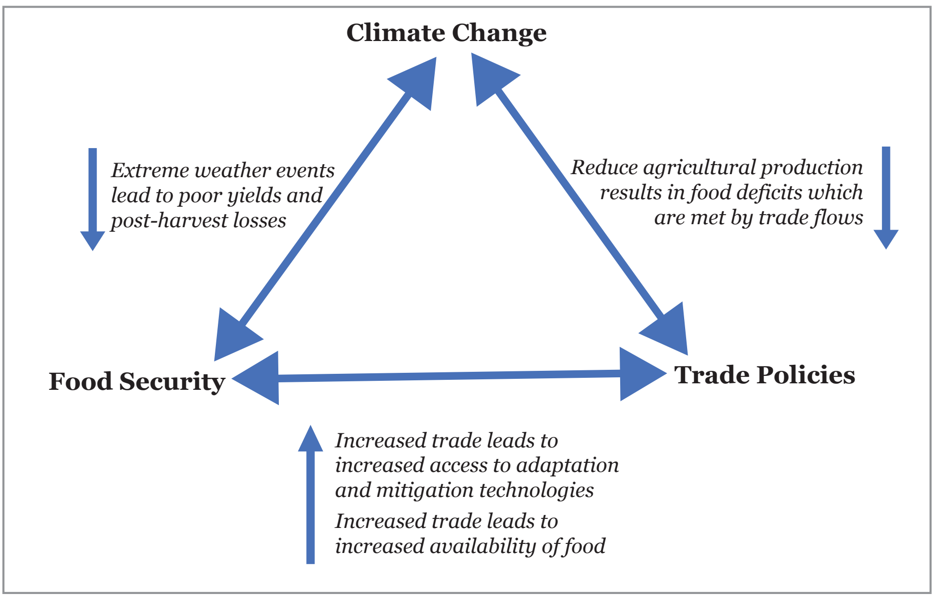
2. Methodology

2.1 Conceptual framework

This study adopted the climate change, agriculture and trade "Nexus" as defined by Balcha & Macleod (2017). The Nexus represents a process by which trade facilitates food security to meet the needs of the rising population in a changing climate. Although agricultural production is vulnerable to climate change, food security is not necessarily a result of low production but a combination of other factors such as poor distribution caused by perverse subsidies and other trade barriers. This tend to be amplified in countries depending on imports for their food security needs such as is the case in many EAC countries.

Extreme climatic events lead to shifts in planting seasons, reduces maturing periods of crops, livestock losses among others. The extreme variations result in reduced production of both crops and livestock hence resulting in high food prices causing food insecurity. This situation enhances trade because there is need to import these products so as to meet the deficit. Open trade expands opportunities for increased availability of food thereby ensuring food security. By so doing, more emissions are generated thereby accelerating the impact of climate change.

Figure 1: The Nexus between Climate change, food security and Trade



Source: Adapted from CUTS international, 2013

Climate change has a direct impact on agricultural trade policies as can be seen in situations where there is a food crisis due to change in weather patterns. Trade liberalization facilitates domestic and cross-border trade and availability of agricultural commodities. Free trade policies may stimulate economic growth through growth in production and expansion of markets, which in turn increase household incomes. Increases in incomes of households has the direct impact of increasing household expenditure on food hence a household has capacity to access more food. On the contrary, trade restrictions, including export/import bans and non-tariff measures inhibit agricultural trade thereby increasing the threat of food insecurity.

2.2 Analytical framework

The analytical framework uses four models that integrate climate change, food production and security, trade and welfare implications. In a first step, simulations of future climate conditions (temperature, rainfall) from Global Climate Models (GCMs) are spatially downscaled and fed into a crop simulation model[2] which assesses the changes in yields for maize in different agro-ecological zones in EAC region. Output from the crop simulation model then informed the spatial equilibrium model (SEM) that was used to estimate the impacts of agriculture and trade policies on household welfare in the region. Finally, the food poverty line was used to determine the situation of food security.

2.2.1 Climate Change Model

Coordinated Regional Climate Downscaling Experiment (CODEX) models were used for generating the climate projections. Dynamic downscaling techniques were used to extract data from General Circulation Models (GCMs) and adapted to local climate conditions (Tadross *et al*., 2005). Downscaled data for the period 1980-2010 and 8 GCMs over the Africa domain, running in transient mode for the period 1951-2100 were used. All simulations were performed at 50 km (0.448°) resolution over the EAC domain. The CORDEX ensemble model was based on the Rossby Centre Regional Climate Model (RCA4) run by Sveriges Meteorologiska och Hydrologiska Institut (SMHI). Nikulin *et al*. (2012) provides detailed information on CORDEX models.

The other data set used included daily observations on precipitation (PPT), maximum temperature (TMAX) and minimum Temperature (TMIN) obtained from the National Meteorological and Hydrological service (NMHS) of Burundi (5 stations), Kenya (7 stations), Tanzania (7 stations), Rwanda (8 stations) and

2 Agricultural Production System Simulator (APSIM, version 7.7)

Uganda (10 stations). The stations represent various Agro-Climatic Zones as shown in Annex A1. The period considered included both historical/past (1971 to 2000) and Future (2016 to 2045 as mid-century and 2071 to 2100 as end century). The future projections use Representative Concentration Pathways (RCPs) scenario 4.5 wm^2 and 8.5 wm^2. The RCP 4.5 assumes a lower carbon dioxide in the atmosphere, while that of RCP 8.5 is higher.

There is lack of high-quality observation datasets at suitable temporal and spatial resolution necessary for evaluating RCM simulations in the EAC region. Therefore, the climate change modelling relied on processed data available at CORDEX data portal.

The ability of the climate model to match the long-term historical climate observations was determined through both graphical and error analysis techniques. Trend analysis was used to determine the spatial and temporal variability of past and future climate over EAC. The change between the projected and baseline yield were determined using the percentage difference technique. The presence of a monotonic increasing or decreasing trend was tested with the nonparametric Mann-Kendall test while the slope of a linear trend was estimated with the nonparametric Sen's method (Gilbert 1987). Furthermore, the true slope of the existing trend (as change per year) was estimated using the Sen's nonparametric method (Salmi *et al.*, 2002; Slack *et al.*, 2003). The tested significance levels alpha (α) are 0.001, 0.01, 0.05 and 0.1.

2.2.2 Crop model simulations

The Agricultural Production System Simulator (APSIM, version 7.7) (Keating et al., 2003; Wang et al., 2002, 2004) was used to simulate the phenology and yield of maize. The APSIM model contains bundled and distributed databases of previously tested crops & soil parameters (Daniel, *et al.,* 2006). In the study, the performance of APSIM model in simulating maize yield was based on modification of two phenology parameters which are thermal time accumulation from seedling emergence to end of juvenile, flowering to maturity. The study selected short, medium and long-term maturity cultivars to evaluate the impacts of climate change in different agro-ecological zones (AEZ); Burundi 5 AEZ, Kenya 7AEZ, Tanzania 9 AEZ, Rwanda and Uganda 4 AEZ each (Appendix 1 - Table A1). The APSIM model was tested against observed farmers yield estimate data from 1971 to 2000. The model parameters were adjusted to reflect the observed yield estimates based on published reports and results compared through graphical analysis.

2.2.3 Spatial Equilibrium Model

The spatial equilibrium model (SEM) assumes production and/or consumption usually occurs in spatially separated regions (in this case Burundi, Kenya, Rwanda, Tanzania, Uganda and Rest of the World (RoW)), each of which have supply and demand relations. In a solution, if the regional prices differ by more than the interregional cost of transporting goods, then trade will occur and the price difference will be driven down to the transport cost (McCarl and Spreen, 1998). Modelling of this situation addresses the questions of: a) who will produce and consume what quantities; and, b) what level of trade will occur. The SEM model comprised of four blocks of equations: supply, demand, consumption and market clearing identities for the six crops (Beans, Maize, Millet, Rice, Sorghum and Wheat) for each of the EAC countries (Appendix 2).

Domestic supply block for the different crops was estimated using the Nerlovian model (Askari and Cummings, 1977; Leaver, 2004; Yu et al., 2010). The Nerlovian model is a dynamic model, stating that output (area) is a function of expected price, output (area) adjustment, and some exogenous variables. The demand block was estimated using the Almost Ideal Demand System (AIDS) (Deaton and Muellbauer, 1980) based on own price and income elasticities of demand. The AIDS specification was used as the basis for an econometric estimation of the demand parameters.

To analyze the impact of agriculture and trade policies and climate change on household welfare in the region, the mixed complementarity problem (MCP) method was used. The impact was captured after introducing changes in exogenous variables of the model, which in turn influences the equilibrium price. Agricultural policies were introduced by changing demand and supply parameters in the supply and demand blocks. Trade policies were introduced by changing import and export prices. Climate change was introduced in to the supply side of the equation. Its effects on area and yield are incorporated into the simulations through the intrinsic output growth rates () as shown in the supply block equations. The impact of policy and climate change on welfare were captured by introducing changes in exogenous variables of the model, which in turn influences the equilibrium price. This change in price is then used in estimating the change in welfare (Appendix 3).

2.2.4 Food poverty Index

Household food poverty was used to give an indication of food security in the EAC countries. The food poverty was measured using the Foster-Greer-Thorbecke (FGT) index (Foster et al. 1984). FGT is used to quantify three elements of poverty, namely: level, depth and severity, which are also, respectively, known as incidence, inequality and intensity of poverty. The FGT index is defined as:

$$P_\alpha (y \mid z) = \frac{1}{n} \sum_{i=1}^{q} \left[\frac{g_i}{z} \right]^\alpha \qquad \textit{Equation 1}$$

$y = (y_1 \ldots\ldots\ldots\ldots\ldots\ldots y_n)$ the individual income

q = q (y; z) number of poor households with income no greater than z

n = n (y) total number of households

α can take the value 0, 1 or 2.

Z > 0 is the predetermined poverty line

g_i = Z - y_i income shortfall in i^{th} household

When α = 0, then $p_0 = \frac{q}{n}$ this is the head count ratio and is the proportion of the population below the specified poverty line. α_0 measures the level or incidence of poverty. When α = 1, this gives the income short fall for a household to move out of poverty, when α = 2, this measures the poverty severity.

In measuring food poverty impacts, some adjustments were made to the definition of the poverty line (*z*). While most studies define poverty line using total consumption expenditure of food and non-food commodities, this study defined the poverty line using food expenditure only, hence transforming the poverty line to a food poverty line. With this definition, it was possible to establish those households that are food poor and hence food insecure. The definition of the following variables in equation (2) changed:

$y = (y_1 \ldots\ldots\ldots\ldots\ldots\ldots y_n)$ is the individual food expenditure

Z > 0 is the predetermined food poverty line

g_i = Z - y_i is food expenditure shortfall in i^{th} household

The changes in household expenditure would enable the establishment of how many people/households fell below/rose above the food poverty line *z*.

2.2.5 Data Sources

Different datasets were used in this analysis. For climate modelling two daily datasets namely observed and CORDEX model data were utilized. The data sets contain precipitation (PPT), maximum temperature (TMAX) and minimum temperature (TMIN). Model output were compared to observed datasets obtained from the national meteorological and hydrological services of Burundi (5 stations), Kenya (7 stations), Tanzania (7 stations), Rwanda (8 stations) and Uganda (10 stations) based on representative agro-climatic zones as shown in Appendix 1. The period considered included both historical (1971 to 2000) and future (2016 to 2045 as mid-century and 2071 to 2100 as end century). The future projections used Representative Concentration Pathways (RCPs) scenario 4.5 wm^2 and 8.5 wm^2.

The spatial equilibrium model data on price, consumption, production, imports and exports, were obtained from various sources including respective national statistical offices, FAO, World Bank, and FEWSNET. The datasets cover the period 1966 and 2015. A description of supply and demand data is annexed Appendices 4 - 5. For estimating food poverty line, the study used household data for the following years; Kenya (2005/06), Uganda (2009/10), Tanzania (2008/09) and Rwanda (2010/11).

3. Overview of Agricultural Production, Consumption Trade and Related Policies

This chapter examines policy coherence in agricultural production and consumption as well as trade in the region. It highlights production and consumption statistics supporting policies. Production focuses on the main food and cash crops as well as the main livestock types. Intra-EAC trade covers food commodities in the period 2011 to 2015.

3.1 Regional Production and Consumption Trends of Selected Crops

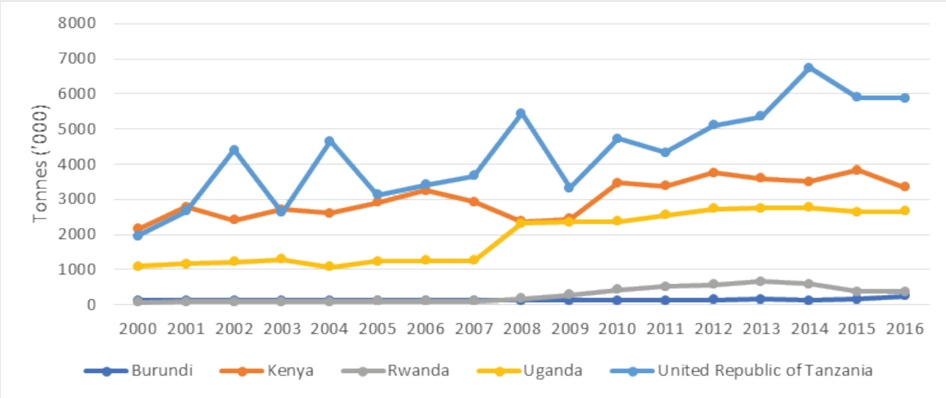
Economies in EAC, just like many African countries, are predominantly dependent on agriculture (CAADP, 2010). Agriculture contributes over 30 per cent of the countries' Gross Domestic Product (GDP) and 60 per cent of all employments. The sector also plays a vital role in contributing towards foreign exchange earnings through exports, and provision of raw materials for agro-based industries in these states. About 80 per cent of the total population in the African countries live in the rural areas, and 75 per cent of them are engaged on agriculture as the key enterprise of the rural economy (EAC, 2006). Therefore, agriculture is not only key to economic growth and development but also critical in reducing the vicious cycle of food insecurity, hunger and poverty prevalent in the rural areas.

Owing to climate variability in different parts of the EAC region, different agro-ecological zones favour production of different food & cash crops, and livestock. Land area coverage for selected crops has shown mixed trends in the last decade in the EAC Partner States. Figures 2-7, presents information on the production (in 000's MT) of main food and cash crops in the region.

3.1.1 Maize Production and Consumption in EAC

Maize is one of the key staple food crops in the Eastern and Southern African region. Its availability in most countries is equated to food security. As presented in Figure 2, the main maize producers in the EAC region are Tanzania, Kenya and Uganda. Tanzania is the region's highest producer of maize, followed by Kenya and Uganda in that order. Rwanda and Burundi produce comparatively small amounts of maize. Before 2009, the production in these two countries had almost stagnated but Rwanda is showing an upward trend in maize productions having been steadily increasing. Although Tanzania has had the highest maize production over the years, it also had the largest fluctuations in production.

Figure 2: Maize production in EAC



Source: FAO, 2017

Except in the years 2010/11 and 2011/12 when production outstripped consumption, in the other years there has been a deficit in the regions' production as shown in Figure 3. Despite the high yield gap, the policy environment in the EAC is considered not conducive for expanding maize production beyond regional maize consumption needs. For instance, in Tanzania, maize producers are isolated from regional markets as a result of periodic export bans, discouraging investment in maize production and resulting in lower farm gate prices. Compared to lower-cost producers (e.g. South Africa), the region is not competitive in maize production, and exceeding the regional consumption would cause a slump in farm gate prices.

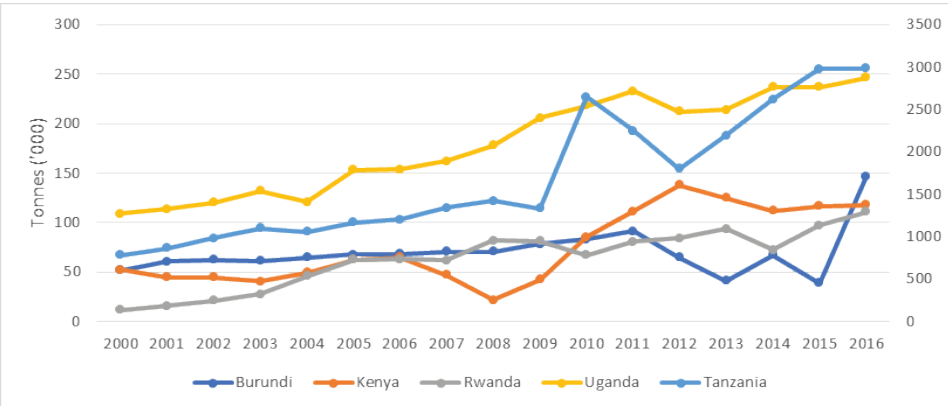
Figure 3: EAC maize production, imports, exports and consumption

Source: USDA (2014)

3.1.2 Rice Production and Consumption in EAC

Rice is the second most important staple in the EAC, after maize, with an annual milled rice production of about 1.25 million MT. Tanzania produces about one million MT (80% of the total regional production), while Uganda produces 130,000 MT. Production in Kenya is slightly above 100,000 MT while Rwanda, and Burundi each produce less than 50,000 MT. Annual production has been increasing by 9% in Tanzania; 11% in Kenya; 6% Uganda and 4% in Rwanda. This growth is as a result of increasing area under rice cultivation rather than from increase in yield (Kilimo Trust, 2014). In Uganda and Kenya, area under rice has been increasing at an average rate of 8% per annum and 5% per annum in Tanzania. The estimate consumption in the region was 1.8 million MT in 2012 with Tanzania having the largest annual consumption of 1.18 million MT, which is equivalent to 65% of EAC total consumption. Kenya is the second largest net consumer at 370,000 MT annually compared to its local production that is estimated to be only 122,465 MT (Mulinge and Witwer, 2012).

Figure 4: Rice production (000's MT)



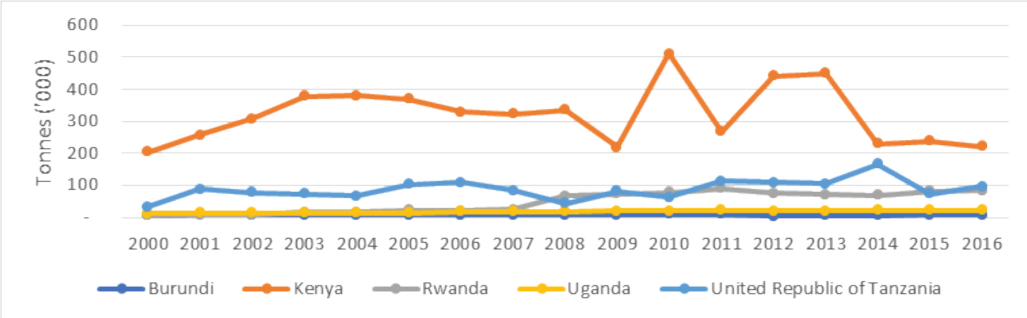
Source: FAO (2017)

3.1.3 Wheat Production and Consumption in EAC

The EAC wheat production has remained below its consumption over the years. For example, Kenya's wheat production is above the 300,000 MT, but the country is only able to meet only 40% of her national wheat demand through direct production (Gitau *et al.*, 2012). Tanzania comes second in total wheat production though her production is below 200,000 MT. The other three EAC partner states; Rwanda, Burundi and Uganda post negligible wheat production levels, but Rwanda is showing some positive gains in wheat production (Figure 5).

It is projected that though per capita wheat consumption in the region has remained fairly constant in the last decade, East African Community (EAC) Member States in coming years will cumulatively import about two million metric tons of wheat annually, double the total from ten years ago. The increase will be occasioned by an increasing EAC population, and marginal increments in EAC wheat production (USDA, 2012).

Figure 5: Wheat production in EAC (000's MT)

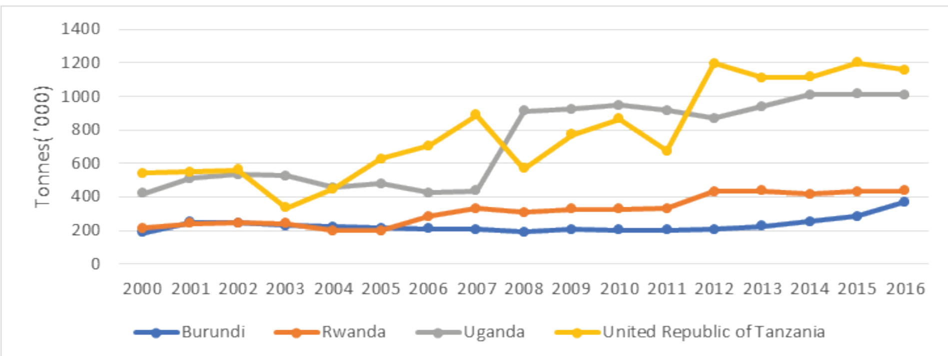


Source: FAO (2017)

3.1.4 Beans Production and Consumption in EAC

The leading producers of beans in EAC are Tanzania (1.1 million MT) followed by Uganda (1 million MT) and Rwanda (400,000 MT) (2014). Bean production in the region faces a number of constraints such as high costs of improved seed, pest and disease prevalence, environmental degradation, inefficient agronomic practices, high post-harvest losses, lack of a pricing structure, low input utilization, as well as poor to lack of extension services. Common bean consumption in Kenya has grown by 19% per annum against production growth of 3% thus creating a deficit of 16 per cent. These deficits are met by imports from Uganda, Tanzania and Central Africa (USAID, 2010b).

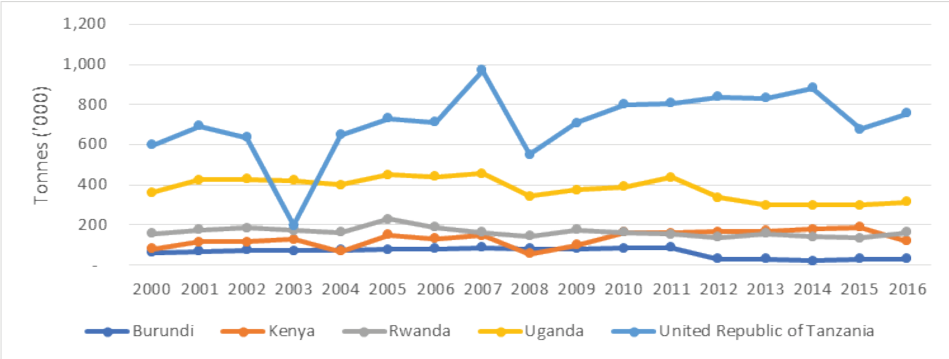
Figure 6: Beans Production in EAC (000's MT)



Source: FAO (2018)

Sorghum is also a major food crop in EAC. Tanzania and Uganda are the leading producers in the region (Figure 7).

Figure 7: Sorghum Production in EAC (000's MT)



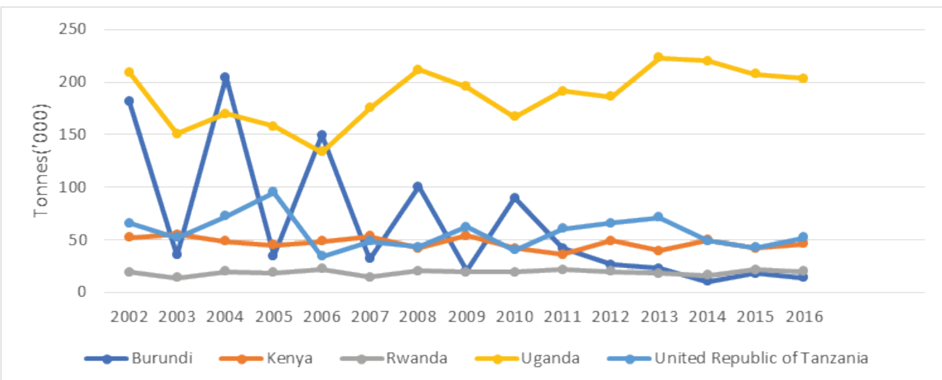
Source: FAOSTAT (2018)

3.1.5 Coffee and Tea Production and Consumption in EAC

Coffee is an important foreign exchange earner in EAC. Both smallholders and large estates produce coffee. About 75% of the acreage under coffee are cultivated by small growers, who account for over half the total regional production. Uganda is the highest coffee producer in the region followed by Kenya and Tanzania.

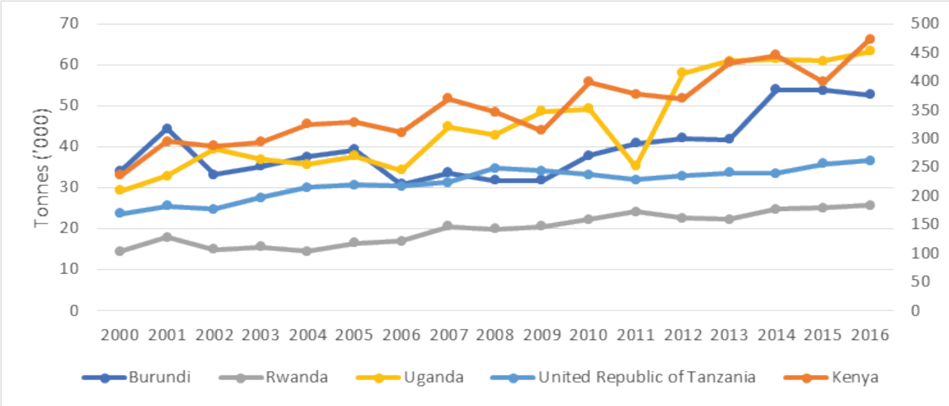
Tea is also a major source of employment, income and foreign exchange. It is normally grown in areas between 1500 and 2700 meters above sea level. This condition confines its production to cool highlands. Kenya is the highest producer of tea in the region. Kenyan small-scale farmers account for 60 per cent of the total tea produced. There are about 420,000 small scale tea farmers in the country. Figures 8 and 9 show coffee and tea production trends in the region, respectively.

Figure 8: Coffee production in EAC



Source: FAOSTAT (2018)

Figure 9: Tea production in EAC (000's MT)

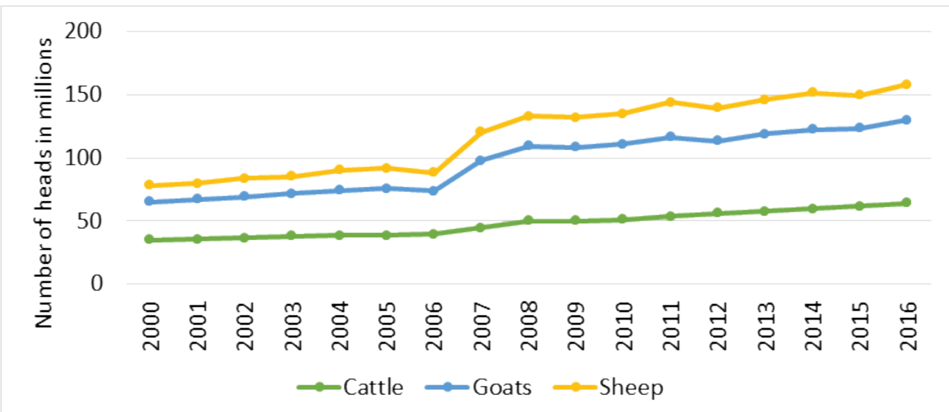


Source: FAOSTAT (2018)

3.1.6 Livestock Production in EAC

The East African Community has enormous animal resources that contribute substantially to the economies of the partner states. The total production of cattle went up from 56 million heads in 2012 to 64 million head in 2016. Goats and sheep registered 3.1 per cent and 9.3 per cent increase, respectively. Tanzania realized significant growth in all livestock except cattle (FAOSTAT, 2018)

Figure 10: Livestock population in EAC



Source: FAOSTAT (2018)

3.2 Agricultural and food security policies

The EAC economies depend largely on agriculture for growth and development (EAC, 2006). The region has high agricultural potential and any development of the agricultural sector presents a great opportunity for hunger and poverty reduction in a sustainable manner through increased productions. Owing to its importance, the EAC countries have come up with agricultural policies and action plans which cuts across the region for the betterment of the sector. They include the following.

3.2.1 EAC Agricultural and Rural Development Policy (EAC-ARDP)

The EAC Agriculture and Rural Development Strategy Policy (EAC-ARDP) was developed in 2006 as an initial step towards realization of the goals of the EAC Treaty on agriculture and Rural Development. The EAC was to mobilize resources and guide the implementation process in an integrated manner. To implement the EAC-ARDP, the EAC Agriculture and Rural Strategy EAC-ARDS (2005-2030) was put in place to provide a framework for improvement of the rural life until 2030. This is to be achieved through increased productivity and production of food and raw materials; improved food security; provision of an enabling environment for improvement of trade; provision of social services such education, health and water; development of support infrastructure, power and communications; and fight against poverty and HIV/AIDS. Under the agricultural sector, the overall objectives of EAC is achievement of food security and rational agricultural production. The development of the EAC-ARDP was therefore a deliberate move by partner states to attain the goals and aspirations set out in the treaty. It also provides a basis for the development of a shared regional vision for sustainable development and takes advantage of the opportunities arising from globalization and regional integration.

To be able to effectively implement the EAC Agriculture and Rural Development Policy, all the regional programs and priorities of the partner states are to be harmonized and supported. Under the agricultural sector, the strategy seeks to achieve food security in the region and improve the standards of nutrition. This is to be achieved by increasing output, quality and availability of food, encourage rational agricultural production with a view of promoting complementarity and specialization and improve standards of living in the rural areas through increased income generation from agricultural production, processing and marketing. In addition, the policy seeks to increase foreign exchange earnings by encouraging production and export of agricultural and fisheries products, support industrialization, encourage the development of new and appropriate technologies that improve the productivity of land and labour, and promote sustainable use and management of natural resources (soil, water, fisheries and forest) to conserve the environment.

The policy also outlines overall objectives and policies for food security, crop production, animal production, fisheries, research, extension and training, forestry, irrigation and water management, natural disasters and land and environment among others. The comparative advantage in the agricultural sector and wide range of resource endowment that exists in EAC offers a considerable socio-economic potential and provides a strong basis for promoting production and trade in agricultural commodities thus ensuring food security in the region. The partner states in the EAC countries are already co-operating on a number of areas in agriculture and rural development such as food security, control of trans-boundary animal diseases, environmental management, and sanitary and phytosanitary issues.

3.2.2 East African Community Food Security Action Plan (2011-2015)

The EAC region is frequently affected by food shortages and hunger despite the fact that the region as a whole has a huge potential and capacity to produce enough food for regional consumption and a large surplus for export to the world market. This can be attributed to high variability in production due to high variability of weather and inadequate food exchange flows (trade) in the region. The EAC- Food Security Action Plan (2011-2015) was developed to guide the implementation and actualization of regional food security. The action plan provides guidance in the coordination and implementation of the joint programmes and projects emanating from the plan. The priority areas for the plan include provision of an enabling policy, legal and institutional framework; increased food availability in good quantity and quality; improved stability of food supply and access; enhancing the efficiency of food utilization, nutrition, and food safety; and development of implementation strategy and monitoring guided by the Agriculture and Rural Development Strategy for the East African Community (2005 - 2030).

The plan also seeks to establish regional policy and standards for food security, improvement of infrastructure especially the rural feeder roads, development of agro-industries for value-addition agro-processing, development of insurance instruments to cushion farmers against agriculture-based risks and establishment of a proper mechanism for continuous food access and utilization.

3.2.3 Draft East African Community Regional Livestock Policy

EAC has enormous animal resources that contribute substantially to their economy and livelihood for livestock keepers, especially pastoralists who form a large proportion of the regional population. The East African Community has embarked on development of a regional livestock policy with the aim of reinvigorating the regional livestock industry. The draft livestock policy aims at unlocking the untapped economic potential of the sector in the region through the formation of a basis for growth of the livestock sector and promoting increased safe production and productivity, prevention and control of diseases. Other objectives include promoting market access, enhancing livestock trade, improving the nutritional base of animals in the region, enhancing and promoting good animal production practices including management of farm animal's genetic resources and other associated livestock requirements like availability of water and marketing infrastructure.

The EAC regional livestock policy is therefore expected to harmonize livestock development issues in the region in line with the EAC integration policy. It will harmonize livestock national laws, control of trans-boundary diseases, and ensure sufficient budgetary allocations to the sector. Poor control of trans-boundary animal diseases at EAC border posts is a major threat to livestock development in the region. Harmonized regional veterinary regulations will enable mutual recognition of veterinary vaccines approved by one regulatory agency.

3.2.4 East African Community Bio-Safety Policy

All the EAC partner states have ratified the Cartagena Protocol on Bio-safety and hence are part of over 133 countries in the world that have agreed to contribute to an adequate level of protection in the field of safe transfer, handling and use of living modified organisms and trans-boundary movements globally. The protocol came into force in September 2003 and the process of implementing the protocol involves putting in place National Bio-safety Frameworks (NBFs). The EAC partner states have already put in place their NBFs following extensive consultations with policy makers, scientists and other stakeholders. The main components of these frameworks include the National Bio-technology/Bio-safety policies and the regulatory regimes. Consequently, the EAC countries have moved a step further and have come up with a regional bio-safety policy which calls for the formulation of a harmonized regional policy on Genetically Modified Organisms (GMOs), establishment of a regional bio-technology and bio-safety unit, the need for mechanisms for resource mobilization to support capacity building and formation of strategies for public education, participation, and awareness in bio-technology and bio-safety issues.

The policy is expected to effectively cut costs and avert duplication in testing and approval procedures of genetically modified substances in the EAC partner states. It will also mitigate the potential impact of GMOs on inter and intra-regional trade and enhance information sharing and/or co-ordination on regulatory approvals on cross border movement of GMOs. It is expected to guide the region on proper use and/or management of GMO crops.

3.3 East African Community Climate Change Policy (EACCCP)

Climate change affect key economic drivers such as water resources, agriculture, energy, transport, health, forestry, wildlife, land and infrastructure among others, and thus to the development of set targets and goals of the EAC region. The EAC partner states developed and adopted a regional East African Community Climate Change Policy (EACCCP) in 2009 to provide a framework for addressing climate-related challenges. The policy seeks to elevate climate change on top of their common agenda and to address it in a coordinated, integrated, and multi-sectoral approach.

The policy is consistent with the fundamental principles of the Treaty establishing EAC and principles of international environmental law according to the EAC Protocol on Environment and Natural Resources, the Protocol on Sustainable Development of Lake Victoria Basin and the United Nations Framework Convention on Climate Change (UNFCCC). The policy is also guided by the emerging issues and challenges faced by the region and potential benefits and opportunities in light of the increasing climate change. The effective implementation of the prioritized climate change adaptation and mitigation measures identified by the policy will depend on collaborative efforts by all relevant actors with a view to minimize the overall impacts of climate change and consequently lead to regional social and sustainable economic development.

The overall objective of the policy is to guide partner states on the preparation and implementation of collective measures to address climate change in the region while ensuring sustainable social and economic development. The policy prescribes statements and actions to guide climate change adaptation and mitigation to reduce the vulnerability of the region and enhance adaptive capacity and build socio-economic resilience of vulnerable populations and ecosystems. In view of the high vulnerability of the EAC region, and with the emerging associated challenges especially food insecurity, the adaptation to climate change is accorded high priority. Under adaptation, the policy aims at implementing urgent and immediate adaptation priorities identified in the National Adaptation Programmes of Action (NAPAs), National Adaptation Plans (NAPs) and climate change strategies. The adaptation priorities include strengthening meteorological services and improving early warning systems; disaster risk management through scaling up of efficient use of water and energy resources, irrigation, crop and livestock production, strengthening pre and post agricultural losses, protection of wildlife and key fragile ecosystems and reducing climate sensitive vector and water borne diseases.

On mitigation, the policy recognizes the negligible contribution of the EAC to global greenhouse gases (GHGs) emissions but commits to, as appropriate, contribute to their reduction by preparing the Nationally Appropriate Mitigation Actions (NAMAs) for sectors with high emission potential. These include sectors such as energy, transport, agriculture, waste management and industry. Such actions should not compromise the region's social and economic development but position it towards transitioning to the low carbon development. Priority mitigation measures include: afforestation, reforestation, promotion of energy efficiency, efficient crop and livestock production systems and clean mode of transport systems, and waste management. It also calls for the region to position itself to tap into opportunities for emission reductions available in global funding mechanisms. Thus, capacity building including financing and technology transfer is the key element in the implementation of the policy. Development and transfer of technology are critical in achieving both the adaptation and mitigation programme in the region. Key areas of focus in the field of technology include enhancing technology development and transfer and supporting research and development capacity. Other capacity building initiatives include introduction of Climate Change issues into school curricula; raising awareness; negotiation skills training and carbon trading and harnessing of indigenous technical knowledge.

Monitoring, detection, attribution and prediction measures have also been identified to effectively monitor, detect and predict climate change scenarios and communicate weather and climate information for adaptation measures in all the climate sensitive socio-economic sectors. Actions prioritized to address these issues include modernization of meteorological infrastructure in the partner states and digitization of climate data. The policy has also identified sectoral policy statements which are considered to be cross-cutting including energy, research and development, and awareness and information management and sharing. It has been proposed that these priority areas should be implemented jointly in order to ensure efficiency and consistency in delivery of the services.

To operationalize the provision made in the policy, each EAC member state is expected to create an enabling environment through development of national policy and strategies, legislative and institutional frameworks. The EAC countries will also establish similar arrangements to compliment and coordinate members including establishing a regional climate change co-ordination structure at the EAC Secretariat. The member countries will also establish an EAC climate change fund with the aim of mobilizing financial resources and instruments of implementing the Policy including the EAC climate change strategy and master plan. The EAC secretariat and other organs and institutions of the community will be in the forefront to ensure successful implementation of the Policy. These include: capacity building in terms of technical skills, knowledge and monitoring tools and technology development and transfer and access to finance.

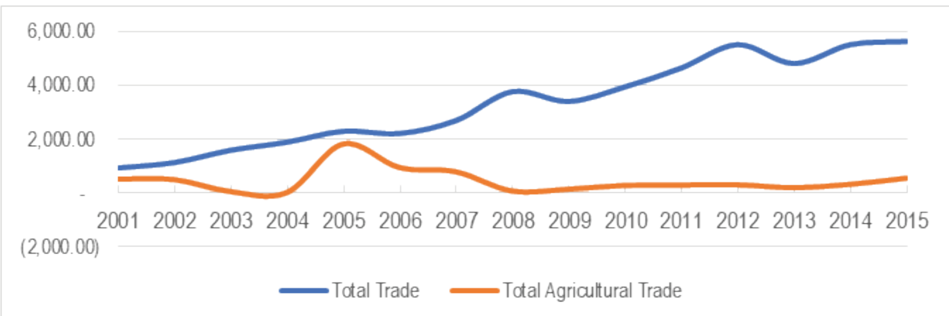
3.4 Trade Policies in the EAC

3.4.1 Intra-EAC Trade

Intra-EAC trade is mainly dominated by agricultural commodities such as coffee, tea, tobacco, cotton, rice, maize, and wheat flour and manufactured goods such as, cement, petroleum products, textiles, sugar, beer and salt. Kenya, Uganda and Tanzania continue to dominate intra-EAC trade even though its value fell from U$$ 5.63 billion in 2014 to US$ 5.1 billion in 2015. The share of intra-EAC trade to the total trade declined to 9.2 per cent from 9.4 per cent in the same period.

Both total and intra-EAC trade have been increasing since the establishment of the customs union. Likewise, the intra EAC trade in agricultural commodities increased sharply in 2005 to US$ 1,800 before declining to US$ 500 in 2008. Since then the value of intra EAC trade on average has been constant at US$ 558 million (Figure 11).

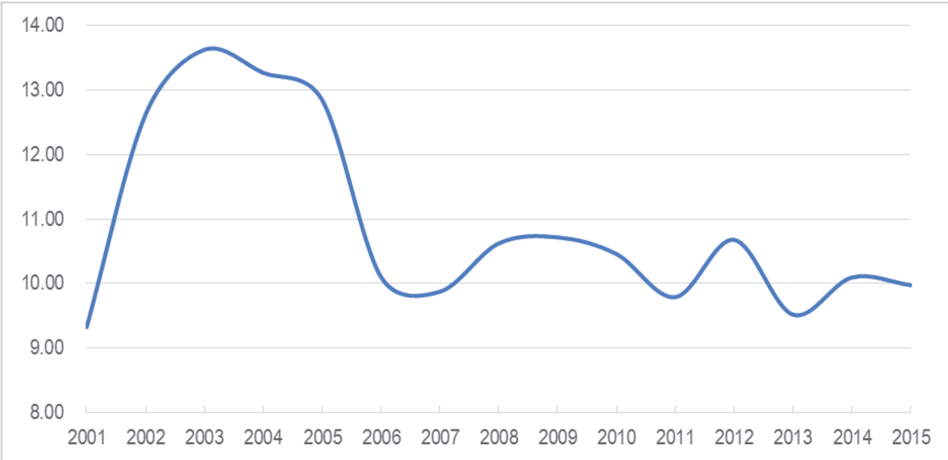
Figure 11: Total Trade in the EAC (Million US$)



Source: ITC Database

Total EAC agricultural trade as a proportion of total EAC trade has remained mixed ranging between 13 per cent in 2006 to 10 per cent in 2015 (Figure 12). One of the main factors that affected agricultural trade was the drought that was experienced in 2008 as well as non-tariff barriers occasionally springing up within the region.

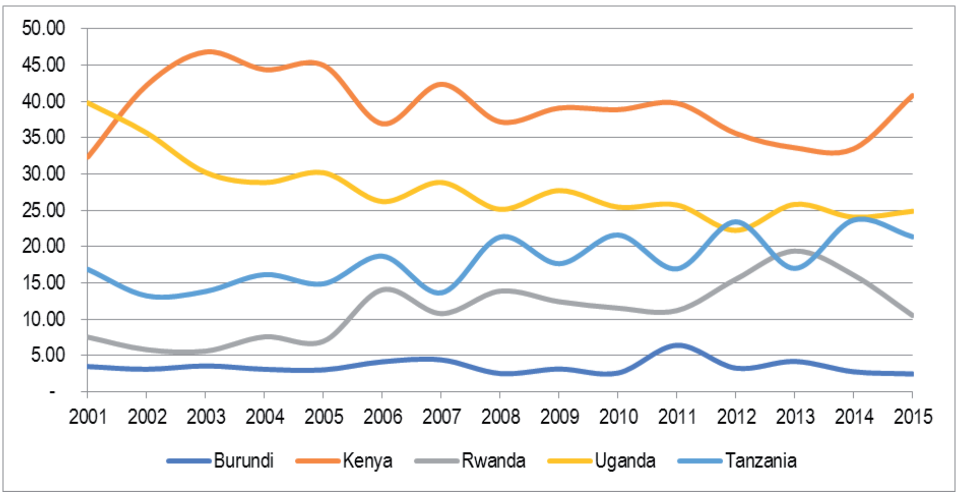
Figure 12: Intra EAC Agricultural Trade as a Proportion of Total EAC Trade



Source: ITC Database

In terms of intra EAC trade as a proportion of total trade for individual countries, the levels are high for Kenya and Uganda which were trading approximately 41 per cent and 25 per cent respectively within the region by 2015. However, on average, only Tanzania and Rwanda have consistently registered increased EAC trade as a proportion of their total trade over the years (Figure 13)

Figure 13: Intra EAC Trade as a proportion of Total Trade



Source: ITC Database

3.4.2 The EAC Common External Tariff

The EAC Customs Union came into effect in 2005 and provides for elimination of internal tariffs and the principle of asymmetry, establishment a common external tariff (CET) in respect of all goods imported into the Partner States from foreign countries and reduction of non-tariff barriers to trade in the EAC region. The EAC countries agreed to eliminate all internal tariffs within a five-year period but while Kenya removed all import duties on imports from Uganda and Tanzania, Uganda maintained duties on 426 tariff lines and Tanzania maintained duties on 906 tariff lines for products in line with the asymmetry principle.

The EAC has a three-band CET with a minimum rate of 0 per cent (raw materials and capital goods), middle rate 10 per cent (intermediate goods) and 25 per cent (finished/manufactured or processed goods). There are exemptions to the CET, where third countries importing to the EAC are charged above the set CET. These products are designated as the sensitive products and require protection from competition given their economic and social importance to the EAC economies. The EAC products designated as being sensitive products are mainly agricultural including milk and cream - 60%; Wheat - 35%; Rice - 75% and Maize - 50%

Article (13) of the protocol stipulates the immediate removal of all forms of non-tariff barriers (NTBs) to importation of goods originating from Partner states. However, elimination of NTBs remains a major challenge as new barriers come into play as the old ones are removed. For instance, EAC NTB Time Bound Programme reported as at 30th June, 2016, Nineteen (19) NTBs remained unresolved; Eight (8) NTBs were reported as resolved; Six (6) NTBs were reported as new; and One Hundred and Six (106) NTBs were reported resolved cumulatively since 2009. Besides, Kenya and the Tanzania assented to the NTB Bill on Elimination of Non-Tariff Barriers in the region in their efforts to eliminate NTBs.

Summaries of the key trade policies (and key features) that affect agricultural production and trade that are being implemented at the regional level are presented in Appendix 6.

3.4.3 Trade Related Aspects

Trade related aspects deal with different issues that affect trade or trade facilitation. Key among them that affect agricultural trade include:

- Rules of origin - this is a criterion for selecting goods that are eligible for community tariff if they originate from the partner states. This is set up in Annex III of the Protocol on the Establishment of the EAC Customs Union. Goods are defined as originating from an EAC country if they meet the following four criteria: a) are wholly produced; b) goods produced in the Partner States and the c.i.f. value of any foreign (that is, non-EAC) materials used does not exceed 60% of the total cost of all materials used in their production; c). Goods produced in Partner States whose value added is at least 35% of the ex-factory cost of the goods; and d). Change in tariff heading.

- National treatment - the partner states must ensure equal treatment of like products of other partner states.
- Trade remedies - these include antidumping, subsidies and countervailing and safeguards measures and how partner states should handle them in relation to third countries and among themselves.

3.4.4 Export Promotion Schemes

The export promotion scheme under the EAC are meant to accelerate development, promote and facilitate export-oriented investments, production of export competitive goods, developing an enabling environment for export promotion schemes and attracting foreign direct investment. There are several schemes in place to promote the set-out objectives including duty draw backs, tax remission, manufacturing under bond and export processing zones.

3.4.5 Trade Related Approaches to Food Security

EAC countries use both food-self-sufficiency and food reliance approaches to meet food deficits depending on various conditions. The former involves attainment of food through enhancement of domestic supplies or export restrictions rather than importations. On the other hand, food self-reliance involves importation of food from cheap producers to meet domestic deficits. For instance, during severe shortages, Kenya temporarily removes all tariffs on food products to allow for increase importations to meet growing demand.

Unlike Uganda, Tanzania and Kenya occasionally issue export restrictions on grains in order to safeguard against depletion of the existing domestically produced stocks. Although these actions disrupt market prices and free flow of agricultural produce, the study by Compete (2011) note that such bans end up encouraging the springing up of parallel markets.

The most common used policies in the EAC to restrict movement of agricultural products are export/import bans/lift and sanitary and phytosanitary (SPS) measures.

Sanitary and Phytosanitary (SPS) measures are normally put in place to protect plants and animals from the risks of entry or spread of pests, diseases, disease-carrying organisms or disease causing-organisms or protect human or animal life from risks of additives, contaminants, toxins or disease-causing organisms in foods, beverages or feedstuffs or any other damages. These standards tend to restrict trade since they are not easy to administer when there are no clear standard or standards are seasonal. SPS become trade restrictive when they are administered in a non- transparent manner or when used by country authorities to prohibit imports of certain commodities without providing the scientific evidence that are required to when doing so.

Standards and technical requirements are aimed to ensure that commodities that enter a country meet a certain criterion for standards. Like SPS, they can also be abused by countries and become a hindrance to trade. For example, in 2016 Kenya through KEPHIS (Kenya Plant Health and Inspectorate Services) imposed charges of plant import permit at Malaba border posts for teas from Uganda and Burundi that are destined for auction at the Mombasa port. At the same time the Ministry of Agriculture in Kenya was not recognizing the SPS certificates issued by Ugandan authorities for tea destined from Mombasa. While these concerns were later resolved, their effect is to raise the cost of doing business for the exporters from Uganda and Burundi. Consequently, lower profit margins result in lower incomes for tea farming households, which increases the risk to food insecurity.

4. Spatial Effects of Climate Change in Agricultural Production

4.1 Descriptive statistics CORDEX ensemble

The coordinated regional downscaling experiment (CORDEX) multimodel ensemble model was compared to selected stations in EAC (Table 1). The mean absolute error (MAE) for precipitation indicated positive values over all stations and ranged from 0.82 to 2.26. Similarly, the normalized root mean square error (nRMSE) showed that CORDEX model over-estimated precipitation over the EAC region. MAE for maximum and minimum temperatures indicated positive and all values below zero over all stations in EAC and thus an indication of small errors existing between modelled and observed maximum and minimum temperature. Assessment of the efficiency of CORDEX model showed that observed mean maximum temperature was a better predictor than the model. However, modified Nash-Sutcliffe Efficiency (mNSE) values over most stations were noted to be centred about zero and thus an indication of model accuracy. Similar results have been shown by Paeth et al. (2011), Nikulin et al. (2012) and Endris et al. (2013) that the multimodel ensemble simulates Eastern Africa climatology adequately and can therefore be used for the assessment of future climate projections for the region.

Table 1: Error analysis of observed and simulated precipitation, maximum temperature and minimum temperature for baseline period

	Precipitation			**Maximum Temperature**			**Minimum Temperature**		
	MAE	nRMSE	mNSE	MAE	nRMSE	MNSE	MAE	nRMSE	mNSE
Kenya	0.97 - 1.44	1.18 – 1.52	-0.71 - -0.32	0.49 – 0.73	1.19 – 1.41	-0.74 – 0.19	0.41 - 74	1.12 – 1.78	-1.08 - -0.22
Uganda	1.12 - 2.26	1.15 – 1.53	-053 – 0.0	0.69 - 0.84	1.26 – 1.32	-0.45 - -0.36	0.6 - 0.77	1.15 – 1.69	-1.15 - -0.15
Tanzania	0.82 – 1.15	1.07 - 142	-0.49 - -0.06	0.48 – 0.63	1.18 – 1.29	-0.3 - -0.18	0.23 – 0.4	1.09 – 1.21	-0.29 - -0.06
Rwanda	1.14 – 2.42	1.25 – 1.60	-0.76 - -0.10	1.53 – 1.97	1.56 – 1.80	-0.92 - -0.57	0.57 – 0.77	1.26 – 1.77	-1.11 - -0.42
Burundi	1.00 – 1.24	1.24 – 1.49	-0.66 - -0.32	1.16 – 1.49	1.54 – 1.87	-0.89 - -0.51	0.37 – 0.55	0.90 – 1.31	-0.44 – 0.05

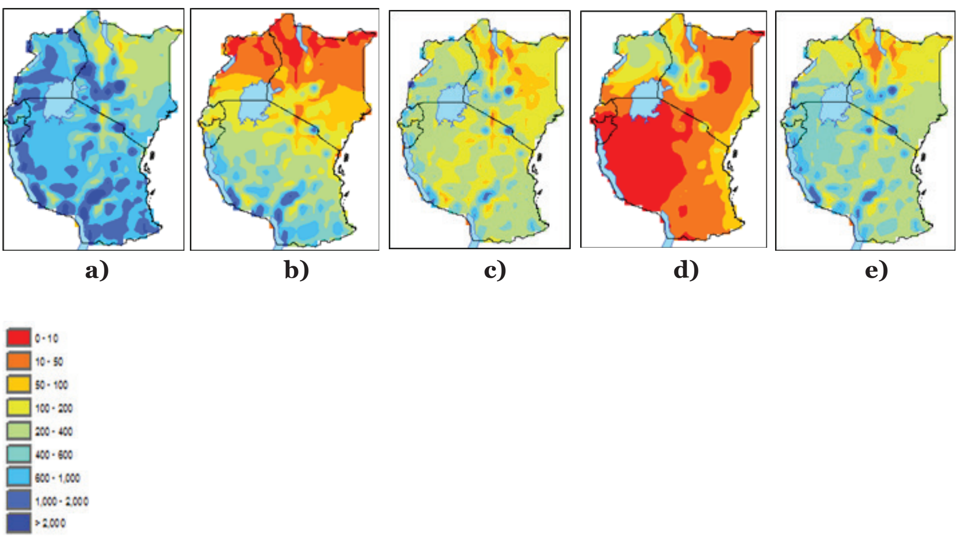
Source: Mukhala, et al. (2017)

Based on these results, the CORDEX ensemble simulates EAC climatology adequately and can therefore be used for the assessment of future climate projections for the region.

4.2 Spatio temporal Analysis of Baseline Climate

Precipitation: The annual baseline precipitation (Figure 14a) indicates high spatial variability of between 100 mm in north eastern Kenya to greater than 2,000 mm over most parts of Uganda, Tanzania, Rwanda and Burundi. Similar patterns of north-east to south west gradient of low to high precipitation are noted for the main rainfall season of March-April-May (MAM) (Figure 14c) and October-November-December (OND) (Figure 14e). During the December-January-February (DJF) (Figure 14b) and June-July-August (JJA) (Figure 14d) seasons, precipitation distribution indicated drier conditions over the north as compared to the south. Previous studies have shown that inter-annual rainfall variability is strongly associated with perturbations in the global sea surface temperatures (SSTs), especially over the equatorial Pacific and Indian Ocean basins (Indeje *et al*. 2000; Black *et al*. 2003; Clark *et al*. 2003 Nyakwada 2009; Omondi *et al*. 2013).

Figure 14: Spatial analysis of a) annual b) DJF c) MAM d) JJA and e) OND baseline precipitation in mm over EAC (1971 -2000)



Source: Mukhala, et al (2017)

Table 2: Trend Analysis of Baseline Precipitation (1971-2000)

Country	Precipitation	
	Slope range	% Δ
Kenya	0.38 - 2.76	10 - 20
Uganda	0.13 - 2.9	-7 - 12
Tanzania	-0.1 - 0.8	-4 - 25
Rwanda	0.28 - 2.49	6 - 22
Burundi	-0.45 - 1.39	-6 - 14

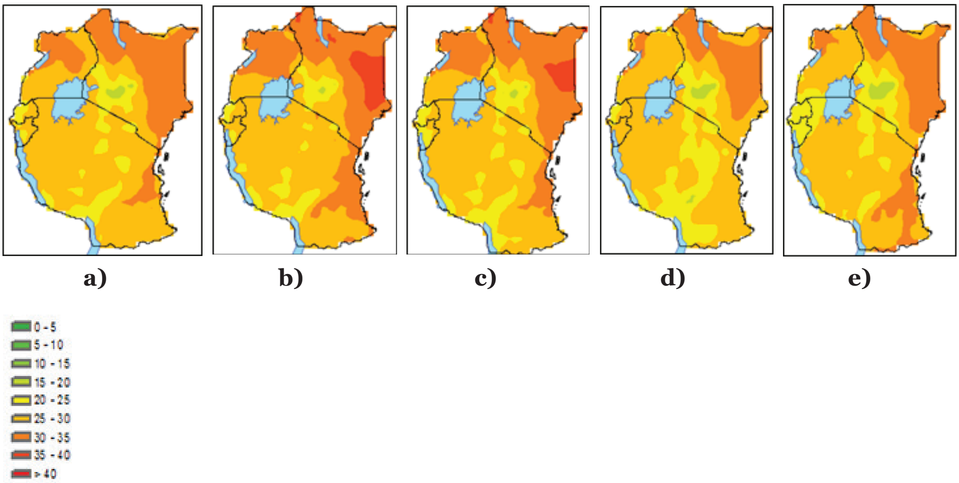
Source: Mukhala, et al (2017)

From the trend analysis, rainfall in EAC is highly variable in both space and time. In Kenya, precipitation showed an increasing trend with computed slope ranging from 0.38 to 2.76 which translated to percentage change in trend that varied from 10 to 20 per cent. In Uganda, precipitation showed increasing trend in Gulu, Soroti, Jinja, Kabale and Mbarara while Kitgum, Lira and Masindi showed decreasing trend. The absolute magnitude of the slope ranged from 0.13 to 2.9 for precipitation while computed percentage change in the trend of precipitation varied from -7 to 12 per cent. In Tanzania, the trend of precipitation showed increase in all stations except Dodoma and Morogoro. The increasing trends were significant at α level greater than 0.1. The magnitudes of the slope ranged from -0.1 to 0.8 while the percentage change in trend of precipitation varied from -4 to 25 per cent.

The trend of precipitation in Rwanda showed an increasing trend. The magnitude of slope ranged from 0.28 to 2.49 while the percentage change in trend of precipitation varied from 6 to 22 per cent. In Burundi, the trend of precipitation was highly varied and were either increasing or decreasing. These trends were significant at α level greater than 0.1 for precipitation. The magnitude of the trend ranged from -0.45 to 1.39 while percentage change in trend of precipitation varied from -6 to 14 per cent.

Annual maximum temperatures: The annual maximum temperatures (Figure 15a) indicated higher temperatures of above 35°C over north Uganda, north-east Kenya and sections of Tanzanian Coast. Similar patterns were observed for DJF (Figure 15b), MAM (Figure 15c), JJA (Figure 15d) and OND (Figure 15e). The locations of intense maximum temperatures were noted to shift slightly during the season. This could be attributed to the location of Inter-Tropical Convergence Zone (ITCZ) which indicates the position of the sun. The central Kenya and parts of central Tanzania recorded lowest maximum temperatures compared to the rest of EAC and could be attributed to the presence of high topographical features such as Mt. Kenya and Mt. Kilimanjaro respectively.

Figure 15: Spatial analysis of a) annual b) DJF c) MAM d) JJA and e) OND baseline maximum temperature in oC over EAC (1971 -2000)



Source: Mukhala, et al (2017)

Table 3: Trend Analysis of Baseline Maximum Temperature (1971-2000)

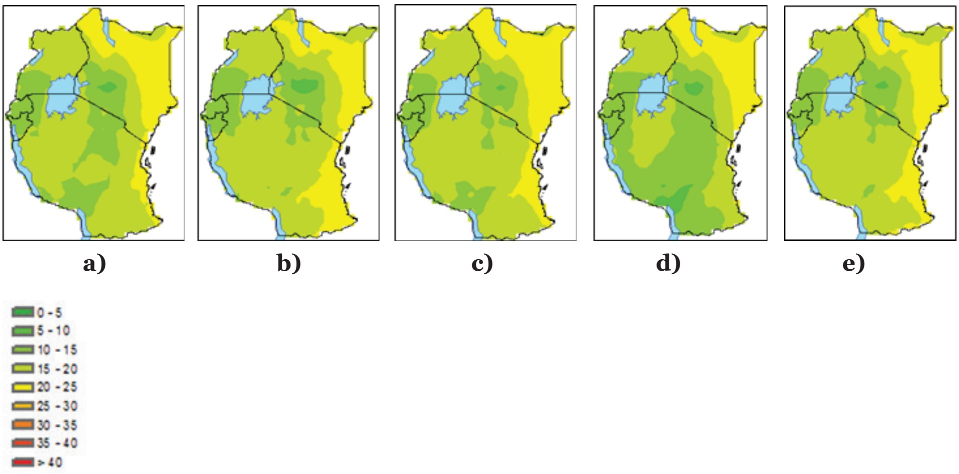
Country	maximum temperature	
	Slope range	% Δ
Kenya	2.57 - 3.53	3 - 8
Uganda	0.01 - 0.02	4 - 6
Tanzania	0.01 - 0.02	5 - 6
Rwanda	0.01 - 0.02	3 - 5
Burundi	0.01 - 0.02	3 - 5

Source: Mukhala, et al (2017)

As indicated in Table 3 maximum temperatures within the EAC show uniform change during the period 1971-2000 with the exception of Kenya which show a higher change ranging between 2.57 to 3.53.

Minimum Temperature: Over EAC region, minimum temperatures were lowest over the west compared to rest of the EAC regions for all seasons (Figure 16a, b, c, d and e). During DJF, lowest temperatures were recorded over central Kenya and highlands west of the Rift Valley. Minimum temperatures for JJA were lowest over in the south of EAC.

Figure 16: Spatial analysis of a) annual b) DJF c) MAM d) JJA and e) OND baseline minimum temperature in °C over EAC (1971 -2000)



Source: Mukhala, et al (2017)

Table 4: Trend Analysis of Baseline Minimum Temperature (1971-2000)

Country	minimum temperature	
	Slope range	% Δ
Kenya	3.21 - 3.96	9 - 16
Uganda	0.01 - 0.02	11 -16
Tanzania	0.02	9 - 13
Rwanda	0.01 - 0.02	13 - 17
Burundi	0.01- 0.02	10 -14

Source: Mukhala, et al (2017)

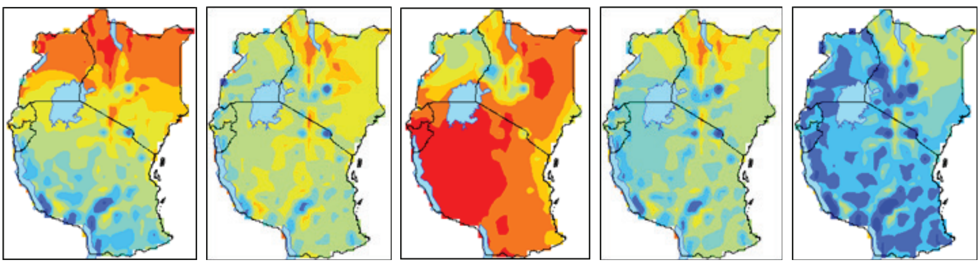
In Kenya, the trends of minimum temperature are increasing with a positive slope ranging from 3.21 to 3.96, while the temperature ranged between 9 to 16 per cent. For the rest of the EAC countries the slope range was minimal while temperature ranged between 9-17 per cent.

4.3 Spatiotemporal Analysis of Future Climate Change

4.3.1 Mid-century and end-century projections based on RCP 4.5

Precipitation: Spatial analysis of projected rainfall based on RCP 4.5 scenario for mid-century (2016-2045) showed that during DJF (Figure 17a), high amounts of about 1,000 mm are expected in the south of EAC, while the north is expected to have a depressed annual rainfall of up to 100 mm. During MAM (Figure 17b), most areas are expected to receive high precipitation. The JJA season (Figure 17c) indicate limited amount of precipitation expected in the region except Uganda and western parts of Kenya. During OND (Figure 17d), only northern Kenya around Lake Turkana are expected to receive depressed rainfall. Figure 17e indicates that annual totals precipitation will be high in most parts of EAC at above 2,000 mm with the north and eastern Kenya being the only areas expected to receive less than 400 mm. Similar patterns are expected for the end century in all seasons (Figure 18 a, b, c, d and e). Notably, the magnitude of expected precipitation will be expected to be less at the end century (2071-2100) as compared to mid-century (2016-2045).

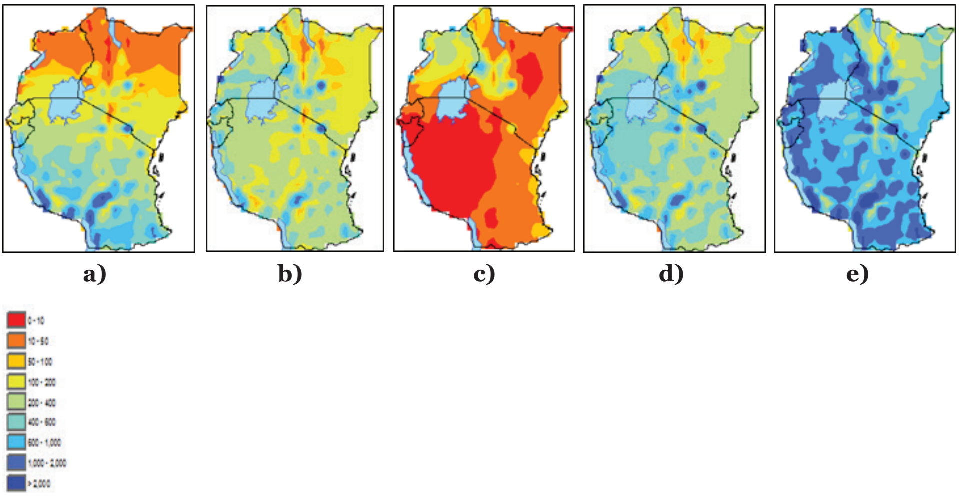
Figure 17: Spatial Analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) annual precipitation in mm based on RCP 4.5 scenario mid-century



a) b) c) d) e)

Source: Mukhala, et al (2017)

Figure 18: Spatial Analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) annual precipitation in mm based on RCP4.5 scenario end-century



Source: Mukhala, et al (2017)

Table 5: Trend Analysis of precipitation based on RCP 4.5 and mid-century and end-century

Country	Scenario	RCP4.5	
	Years	Slope range	% Δ
Kenya	2016 - 2045	-3.83 - 0.27	-20 - 6
	2071 - 2100	-2.24 - 2.56	-52 - 17
Uganda	2016 - 2045	-3.19 - 0.6	-22 - 5
	2071 - 2100	-0.59 - 1.91	-2 - 18
Tanzania	2016 - 2045	0.12 - 6.23	-7 - 43
	2071 - 2100	-4.17 - 0.39	-22 - 24
Rwanda	2016 - 2045	-4,05 - 0.52	-36 - 5
	2071 - 2100	1.1 - 5.53	-20 - 35
Burundi	2016 - 2045	-4.28 - 0.2	-26 - 2
	2071 - 2100	-1.04 -0.13	-9 - 9

Source: Mukhala, et al (2017)

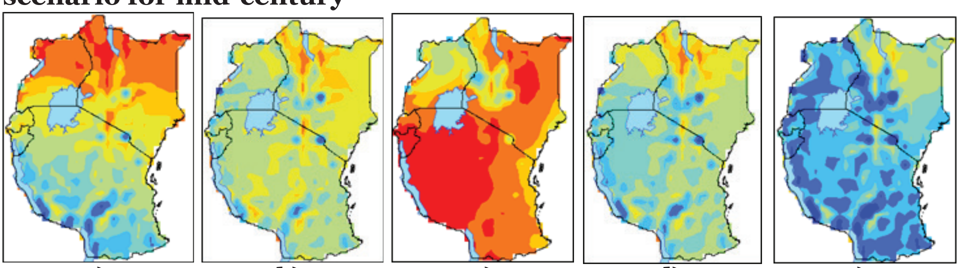
Table 5 shows that rainfall is highly variable in both space and time. For Burundi, mid-century precipitation projections indicated a decreasing trend for all stations except Muyinga. End-century projections show a similar trend except for Nyanza Lac. For Kenya, the mid-century scenario showed increased trend in Kisii, Thika and Makindu and decreased trend in Kakamega, Eldoret and Nakuru. Projections for end century scenario for all stations showed decreasing trend except for Kakamega, Eldoret and Nakuru. The mid-century precipitation projections for Rwanda for all stations will be decreasing except Gabiro and Ruhuha. For end-century, precipitation in all stations will be decreasing except for Ruhuha.

Mid-century projections for Tanzania show increasing trend in all selected stations except Kigoma, while for end-century scenario, increasing trend of precipitation were noted for Arusha and Kigoma. For Uganda, the mid-century projections all stations except Mbarara indicated a decreasing trend. End-century scenario for all stations indicated an increasing trend except for Lira and Kabale.

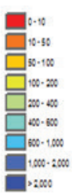
4.3.2 Mid-century and end-century projections based on RCP 8.5

Spatial analysis based on RCP 8.5 scenario for mid-century period showed that DJF precipitation is concentrated in the south of EAC with northern areas expecting less precipitation of up to 10 mm. In MAM the western parts of EAC will be expected to receive more rainfall compared to eastern parts (Figure 19 b). Moreover, most parts of EAC are expected to receive depressed rainfall during JJA (Figure 19 c) except western Kenya and Northern Uganda. During OND (Figure 19 d), most of the southern parts of EAC are expected to receive more rainfall compared to the north. In overall, annual precipitation are expected to be high in excess of 2,000 mm in Tanzania, Uganda, Rwanda, Burundi and western Kenya. Similar precipitation patterns are expected at the end of the century for all seasons (Figure 20 a, b, c, d, and e).

Figure 19: Spatial Analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) Annual precipitation in mm based on RCP 8.5 scenario for mid-century

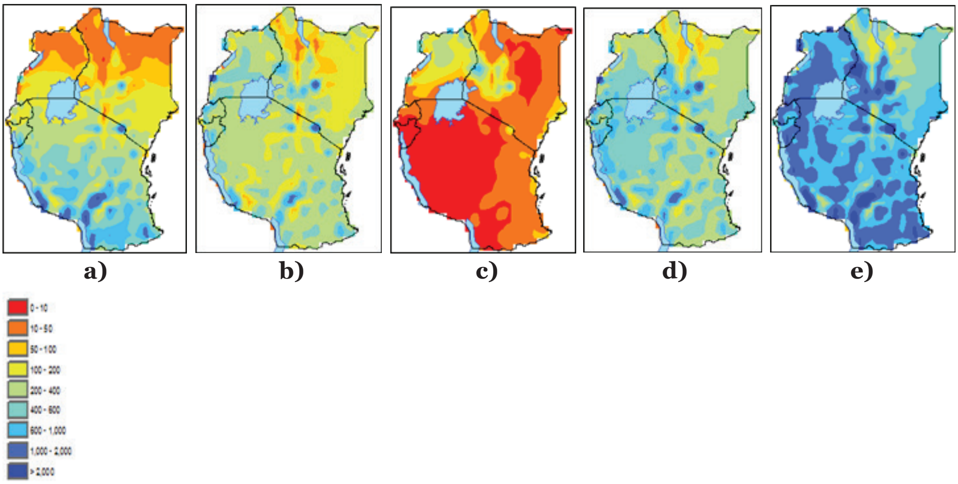


a) b) c) d) e)



Source: Mukhala, et al (2017)

Figure 20: Spatial Analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) Annual precipitation in mm based on RCP 8.5 scenario end-century



Source: Mukhala, et al (2017)

Table 6: Trend Analysis of precipitation based on RCP 8.5 scenarios mid and end-century

Country	Scenario	RCP8.5	
	Years	Slope	% Δ
Kenya	2016 - 2045	-0.14 -2.13	-3 -21
	2071 - 2100	-1.67 - 3.29	-7 - 47
Uganda	2016 - 2045	1.22 - 7.45	10 - 33
	2071 - 2100	-0.26 - 3.24	-15 - 71
Tanzania	2016 - 2045	0.48 - 6.19	17 - 51
	2071 - 2100	-0.64 - 1.29	-7 - 27
Rwanda	2016 - 2045	1.1 - 5.53	-20 - 35
	2071 - 2100	-3.47 - 0.15	-14 - 1
Burundi	2016 - 2045	0.56 - 2.37	-3 - 23
	2071 - 2100	0.69 - 4.18	0 - 40

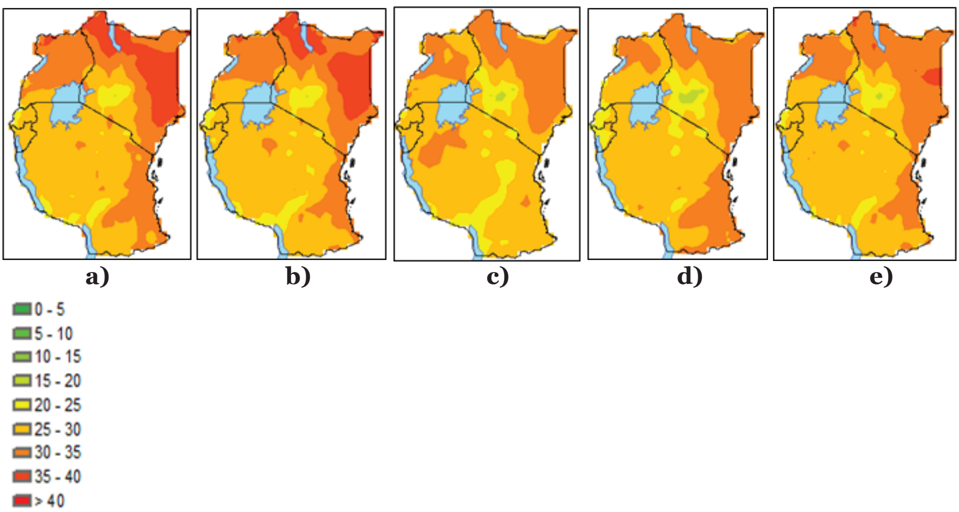
Source: Mukhala, et al (2017)

The temporal analysis shows that in Kenya, mid-century precipitation will increase all in all stations except for Meru. Similar trend will be expected in all stations in Tanzania except Kigoma and Kia. All stations in Uganda will also show increasing trend except Masindi and Kabale. In Rwanda, precipitation will be expected to increase in all stations except Gisenyi, Save and Ruhuha. Scenario for Burundi showed that only Bujumbura and Gisozi will experience positive trends. For the end-century, precipitation across the EAC region will increase except for Musasa in Burundi.

4.3.3 Maximum Temperature for RCP 4.5 and RCP 8.5

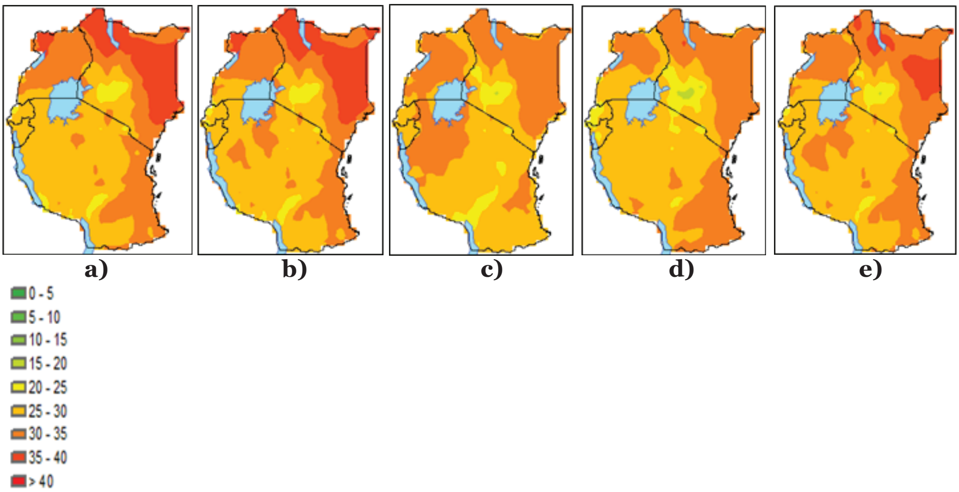
Spatial analysis of projected maximum temperature for RCP 4.5 scenario for mid-century (Figure 21) indicated higher temperatures in north and eastern Kenya, Northern Uganda and along the coast of Kenya and Tanzania while western Kenya, eastern Tanzania, Rwanda and Burundi were observed to have lower temperatures. Lowest temperatures in both seasonal and annual means were recorded in central Kenya. Similar patterns were observed for RCP 8.5 scenario (Figure 22). Worth noting, the magnitude of maximum temperature had increased from RCP 4.5 to RCP 8.5 scenario. Spatial analysis of projected maximum temperature for RCP 8.5 scenario for mid-century (Figure 23) indicated higher temperatures in most parts of EAC which included Uganda, north, east and coast of Kenya and coast of Tanzania. However, for RCP 8.5 scenario for end century (Figure 24), most areas are expected to experience higher temperatures of above 30^{o}C with northern Uganda, north and eastern Kenya showing maximum temperatures greater than 35^{o}C.

Figure 21: Spatial Analysis of Maximum Temperature in oC during a) DJF b) MAM c) JJA d) OND seasons and e) Annual based on RCP 4.5 scenario mid-century



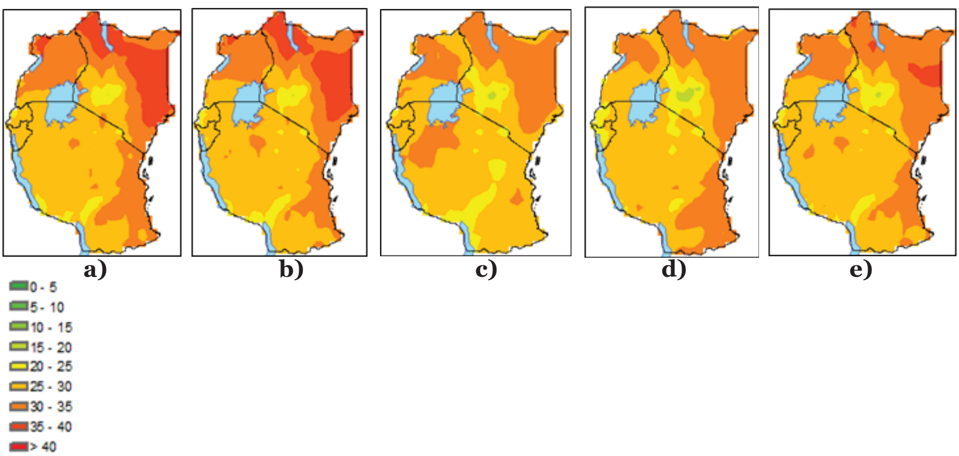
Source: Mukhala, et al (2017)

Figure 22: Spatial Analysis of Maximum Temperature in oC during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 4.5 scenario end-century



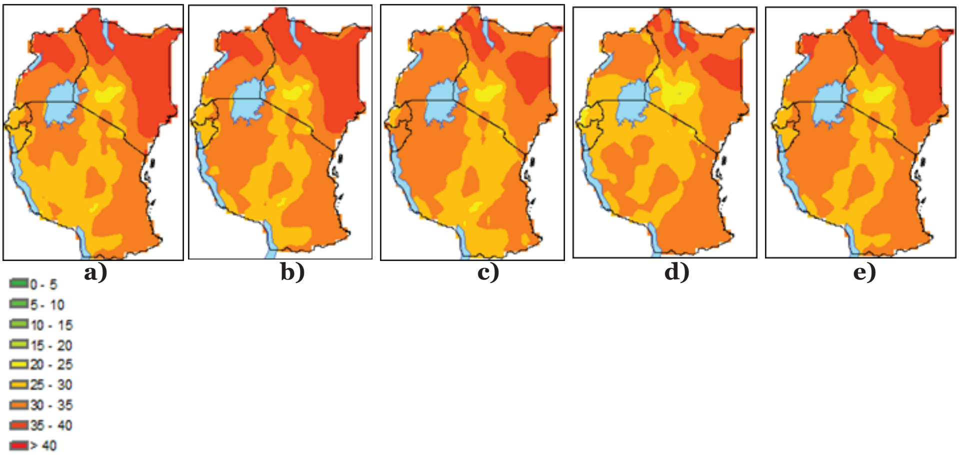
Source: Mukhala, et al (2017)

Figure 23: Spatial Analysis of Maximum Temperature in oC during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 8.5 scenario mid-century



Source: Mukhala, et al (2017)

Figure 24: Spatial Analysis of Maximum Temperature in 0C during a) DJF b) MAM c) JJA d) OND seasons and e) Annual based on RCP 8.5 scenario end century



Source: Mukhala, et al (2017)

Table 7: Trend Analysis of Baseline Maximum Temperature end century

Country	maximum temperature	
	Slope range	% Δ
Kenya	2.57 - 3.53	3 - 8
Uganda	0.01 - 0.02	4 - 6
Tanzania	0.01 - 0.02	5 - 6
Rwanda	0.01 - 0.02	3 - 5
Burundi	0.01 - 0.02	3 - 5

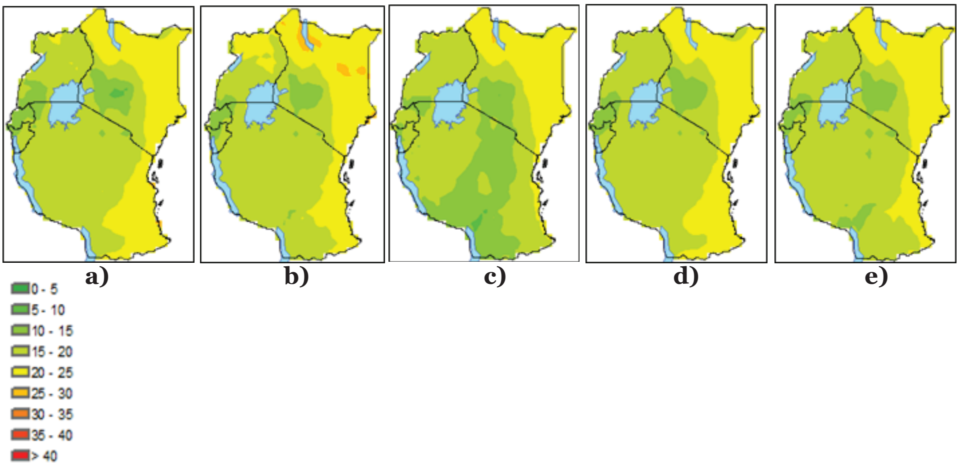
Source: Mukhala, et al (2017)

Temporal analysis of mid-century and end-century maximum temperature for both RCP 4.5 and RCP 8.5 scenario indicated an increasing trend in temperature in all selected stations in EAC.

4.3.4 Minimum Temperature for RCP 4.5 and RCP 8.5

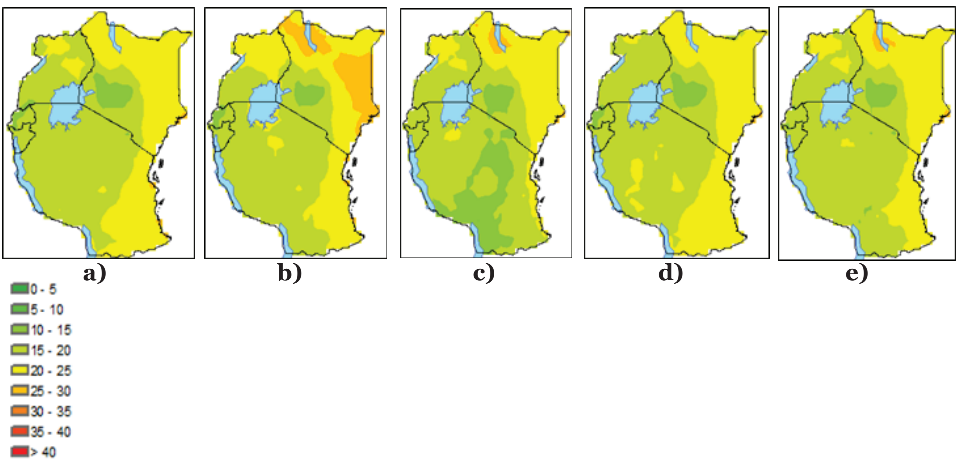
The temporal analysis of mid-century projected minimum temperature under both RCP 4.5 and RCP 8.5 scenarios showed that the trends in all selected stations were increasing. However, projected minimum temperatures were noted to be higher towards end-century for RCP 8.5.

Figure 25: Spatial Analysis of Minimum Temperature in 0C during a) DJF b) MAM c) JJA d) OND seasons and e) Annual based on RCP 4.5 scenario mid-century



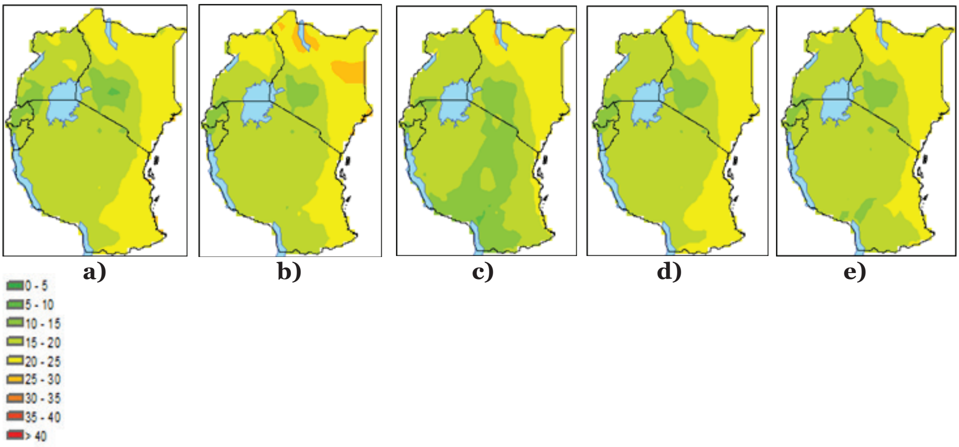
Source: Mukhala, et al (2017)

Figure 26: Spatial Analysis of Minimum Temperature in 0C during a) DJF b) MAM c) JJA d) OND seasons and e) Annual based on RCP 4.5 scenario end-century



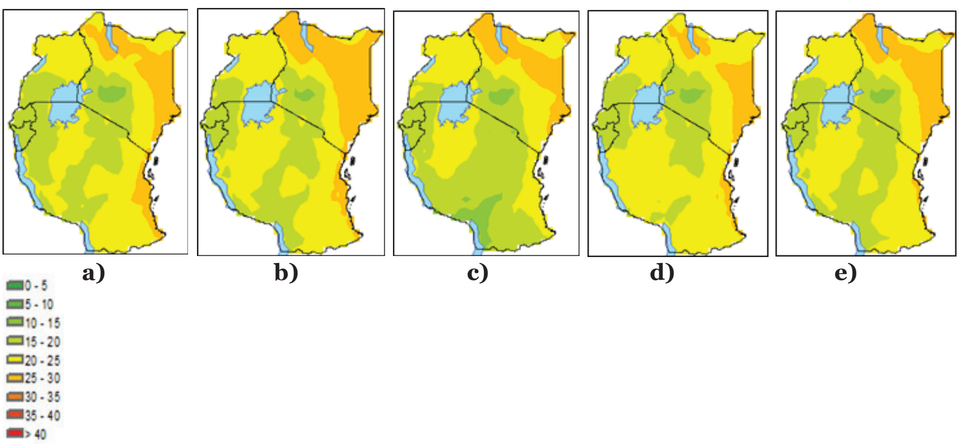
Source: Mukhala, et al (2017)

Figure 27: Spatial Analysis of Minimum Temperature in 0C during a) DJF b) MAM c) JJA d) OND seasons and e) Annual based on RCP 8.5 scenario mid century



Source: Mukhala, et al (2017)

Figure 28: Spatial Analysis of Minimum Temperature in 0C during a) DJF b) MAM c) JJA d) OND seasons and e) Annual based on RCP 4.5 scenario end century



Source: Mukhala, et al (2017)

4.4 Local Impacts-Crop simulation model

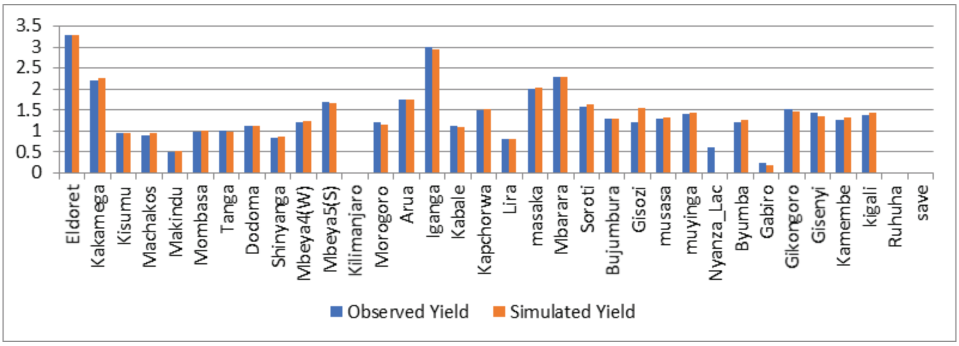
This section presents the results of the APSIM model for maize using climate projections up to mid-century at RCP 4.5 and RCP 8.5 (Table 8). The results show that increasing the thermal time accumulation from flowering to maturity reduces the simulated yields whereas, increasing the thermal time from seedling emergence to end of juvenile increases the simulated yields. Moreover, it was possible to match the simulated maize yield to observed farmers yield estimate through modification of the two phenology parameters (Figure 29) (Loecke *et al.* 2004).

Table 8: APSIM modified maize phenology parameters

Country	Thermal time accumulation from flowering to maturity (oCd)	Thermal time from seedling emergence to end of juvenile (oCd)
Kenya	150 - 450	225 - 535
Uganda	150 - 300	400 - 990
Tanzania	100- 300	315 - 1000
Rwanda	100 - 350	550 - 850
Burundi	200 - 350	450 - 800

Source: Mukhala, et al (2017)

Figure 29: Comparison of Observed (actual) and simulated yields in EAC



Source: Mukhala, et al (2017)

Table 9 presents analysis on effects of climate change on maize production in EAC. The statistics are based on the baseline and projected climate change. The analyses indicate that maize production remains variable in different agro-ecological zones (ACZ) in the region. The projected climate change is expected to increase the gap in maize yield produced in the different ACZ in EAC. Therefore, climate change will result to decreased yield per hectare in some of the ACZ whereas in other ACZ, it will lead to increased maize yield. It is worth noting that there exist other factors that influence crop production such as varietal specifications, edaphic (soil), biotic, physiographic and socio-economic factors.

Table 9: Effects of climate change on maize yields (APSIM)(t/ha)

Country	Baseline (1971-2000)	RCP4.5 (2016-2045)	RCP8.5 (2016-2045)
Kenya	0.51 - 3.29	0.0 - 4.7	0.10 - 4.60
Uganda	0.81 - 2.95	1.1 - 3.3	1.10 - 2.70
Tanzania	0.85 - 1.66	0.5 - 2.9	0.80 - 3.20
Rwanda	0.17 - 1.45	1.6 - 4.0	1.80 - 2.10
Burundi	1.28 - 1.54	2.2 - 4.0	- 1.42

Source: Mukhala, et al (2017)

According to the Table 9, Burundi and Rwanda will gain more from climate change in the mid-century for RCP4.5 and RCP8.5. The minimum yield will increase from 1.28 t/ha in the baseline to 2.2 t/ha in RCP 4.5 but decline to 0.22 t/ha under RCP8.5, while for maximum will increase from 1.54 t/ha to 4.0t/ha at RCP4.5 but decline to 1.42 t/ha at RCP8.5. Generally, across the EAC, the RCP4.5 at the mid-century will have positive yield increases compared to RCP8.5.

5. Impacts of Agriculture, Trade Policies and climate change on Household Welfare

This section presents results of the analysis of the agriculture, trade policies and climate change on welfare in EAC in the mid-century. It starts by first describing the baseline situation for supply, demand and trade response and transposing them to mid-century. The changes in baseline situation are presented with the introduction of agriculture policy, trade policy, and climate change. The section concludes by examining the impacts of climate change on food poverty.

5.1 Baseline Household welfare due to price changes

The baseline for household welfare for the mid-century is based on the production and demand of maize and other cereals in the region. The production was estimated using baseline data for 1961 to 2015 and a similar trend assumed to continue until the year 2045. The projected results show that some crops namely, beans, sorghum and wheat will experience declining production in Burundi, while sorghum and millet will experience declining production in Rwanda and Uganda, respectively. The other crops are experiencing growth in production. Supply is also influenced by producer price which is expected to increase by an average of 1.43-fold and 3.19-fold per annum for all staples in the region.

Table 10: Natural supply growth and producer price changes (folds) in 2045

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	-0.24	1.98	2.29	1.55	4.87
Maize	0.54	3.04	6.70	7.49	3.57
Millet	0.39	6.62	7.92	-1.29	0.20
Rice	2.92	3.75	8.90	8.52	6.48
Sorghum	-1.52	1.22	-0.51	0.66	2.10
Wheat	-0.75	4.27	11.39	3.69	0.78
Producer Price	2.59	1.43	3.19	2.27	2.38

Source: Mulwa (2017)

In terms of demand, historical data for the past 30 years was used to estimate a demand trajectory assuming that status quo continues. The assumptions are that in the mid-century, population and per capita income (expenditure) are expected to change and grow by different magnitudes per annum. Population growth in EAC will grow by between 2.65 and 3.7 per annum, while per capita expenditure will grow by between 1.12-fold and 5.28-fold. Consumer prices are also expected to increase by between 3.51-fold and 5.71-fold per annum (Table 11). Import and export prices are expected to increase by 2% per annum for all the countries.

Table 11: Demand side assumptions in 2045

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Expenditure	1.12	4.87	2.70	5.28	2.11
Population growth rate	3.72	2.70	2.65	3.41	2.91
Consumer Price	4.22	5.71	4.25	3.51	4.78

Source: Mulwa (2017)

It also is expected that commodity supply will change even without specific policy intervention. This is natural supply growth. FAO statistics indicate that supply of these different crops has been growing at varying rates in the different EAC Partner States. Using FAO production data sets from 1961 to 2015, we estimated the average annual growth rate and assumed a similar trend till the year 2045.

Production trends for the last 30 years are shown in Table 12, where some crops such as beans, sorghum and wheat experience declining production in Burundi, while sorghum and millet are experiencing declining production in Rwanda and Uganda, respectively. The other crops are experiencing growth in production. Supply will also be influenced by producer price which is expected to increase by an average of 1.43 per cent and 2.59 per cent per annum for all cereals in the region.

Table 12: Natural Supply growth in producer price changes in 2045

Crop	Country				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	-0.24	1.98	2.29	1.55	4.87
Maize	0.54	3.04	6.70	7.49	3.57
Millet	0.39	6.62	7.92	-1.29	0.20
Rice	2.92	3.75	8.90	8.52	6.48
Sorghum	-1.52	1.22	-0.51	0.66	2.10
Wheat	-0.75	4.27	11.39	3.69	0.78
Producer price	2.59	1.43	3.19	2.27	2.38

Source: Mulwa (2017)

These changes were introduced in the base model to determine the change in welfare and trade flows after 30 years if status quo does not change i.e. we do not introduce new trade and agricultural policies in the region till the year 2045. Further, we assume that intra-regional trade is without trade barriers but international trade between the rest of the world and EAC has barriers in the form of common external tariff (CETs). However, most of the staple crops are considered as sensitive products thus exempted from the CET. The rice imports to EAC attract an external tariff of 75 per cent ad valorem or US$ 345 per ton, whichever is higher. Maize is classified among the sensitive commodities and attracts a 50 per cent duty on imports from other countries. Millet, sorghum and beans attract 25 per cent import tariff when imported from countries without the region (EAC, 2012). Tariff barriers have largely been eliminated in intra-EAC trace but there remains some non-tariff barriers (NTBs) which influence trade. For this analysis however, only tariff barriers were considered due to the difficult in estimating NTBs in EAC.

The results of percentage price changes are presented in Table 13. Price increases are for maize in Kenya, Uganda, and Rwanda; beans in Rwanda; and wheat in Burundi. In all countries, the price of rice will be lower than it is now as supply is projected to outstrip demand. This is also true for millet in all countries except Uganda where demand will outstrip supply.

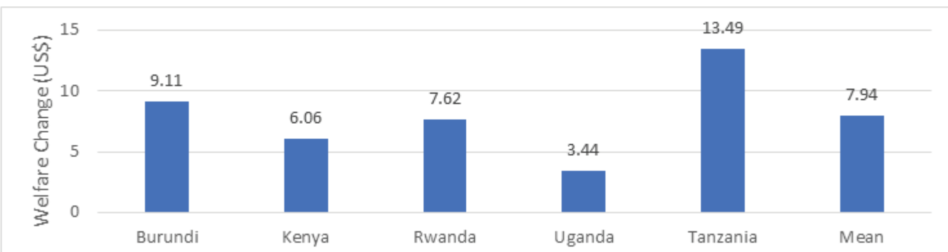
Table 13: Percentage change in price for base scenario in mid-century

Crop	EAC Partner States				
	Burundi	**Kenya**	**Rwanda**	**Uganda**	**Tanzania**
Beans	-10.4	-15.7	2.9	-9.4	-32.1
Maize	-31.6	12.8	5.6	9.7	-1.4
Millet	-26.2	-29.5	-38.5	7.5	-39.4
Rice	-66.1	-47.1	-62.7	-50.1	-46.4
Sorghum	-42.1	-32.7	-14.9	5.5	-50.7
Wheat	3.0	-6.1	-26.3	-18.6	-7.7

Source: Mulwa (2017)

The total welfare changes in the region if business as usual continues by mid-century is shown in Figure 30. The results show, the region will have positive welfare gains. On a country-by-country analysis, all countries have different welfare gains but the EAC mean is US$ 7.94.

Figure 30: Baseline per capita change in welfare due to price changes in mid-century



Source: Mulwa (2017)

Due to changes in demand and supply in the different countries overtime, demand for commodities is expected to rise and so is supply. In countries where demand exceeds supply, imports for specific commodities can be from EAC or rest of the world. In cases where supply exceeds demand, individual countries will export to EAC or rest of the world (RoW) depending on the most profitable option. Table 14 shows intra-EAC trade flows for different commodities. For example, Tanzania will export beans to Rwanda and Burundi. Kenya will import a bulk of its maize deficit from Uganda, and some from Tanzania, as these two countries are expected to have maize surpluses. Kenya imports rice from Tanzania, Rwanda and Uganda. Kenya, Rwanda and Uganda will supplement their beans from rest of the world. Table 15 show the trade between EAC and the rest of the world.

Table 14: Intra-EAC trade flows for base model in the mid-century

	EAC Partner States		
Commodity	**Origin**	**Destination**	**Quantity (000s) MT**
Beans	Tanzania	Burundi	197.09
Beans	Tanzania	Rwanda	206.03
Maize	Burundi	Rwanda	6.44
Maize	Uganda	Kenya	2140.78
Maize	Tanzania	Kenya	292.77
Millet	Kenya	Uganda	27.13
Millet	Rwanda	Uganda	8.92
Millet	Tanzania	Burundi	12.97
Millet	Tanzania	Uganda	100.98
Rice	Burundi	Uganda	19.48
Rice	Rwanda	Kenya	95.76
Rice	Uganda	Kenya	330.93
Rice	Tanzania	Kenya	170.75
Sorghum	Tanzania	Burundi	72.17
Sorghum	Tanzania	Kenya	90.75
Sorghum	Tanzania	Rwanda	154.34
Wheat	Tanzania	Burundi	40.41

Source: Mulwa (2017)

Overall the region will be self-sufficient in maize and rice but will have to import from the RoW millet, sorghum and wheat. Only Tanzania will be self-sufficient in all these products.

Table 15: Grain trade flows with the rest of the world for base model in the mid-century

Commodity	Imports and Exports from RoW		
	Origin	**Destination**	**Quantity (000s) MT**
Beans	ROW	Kenya	1883.15
Beans	ROW	Rwanda	615.36
Beans	ROW	Uganda	1531.85
Millet	ROW	Uganda	576.77
Sorghum	ROW	Kenya	71.60
Sorghum	ROW	Uganda	360.63
Wheat	ROW	Kenya	4452.11
Wheat	ROW	Rwanda	189.33

Source: Mulwa (2017)

5.2 Effect of agricultural policy on Household welfare

The agricultural policy is introduced in the baseline model to examine its effect on household's welfare. The policy assumed that the EAC Partner States spend at least 10 per cent of their budgets in agriculture and attract more than 8 per cent of its FDI in sector in line with the Maputo/ Malabo declaration. This will increase inputs use, irrigation and ultimately production. ASARECA (2007) projects that all agricultural subsectors such as staples, cash crops, and livestock will grow by an average of 5 per cent, per capita income will grow by more than 3.5 per cent while the GDP will grow by an average of 6 per cent. Based on this a growth of 5 per cent to staple production and a uniform 3.5 per cent increase in per capita income is introduced in all Partner States. In addition, it assumed that the population growth will adjust to conform to this period. Trade conditions are assumed to remain the same as the baseline. Based on the implementation of the policy, prices of different commodities will change as shown in Table 16.

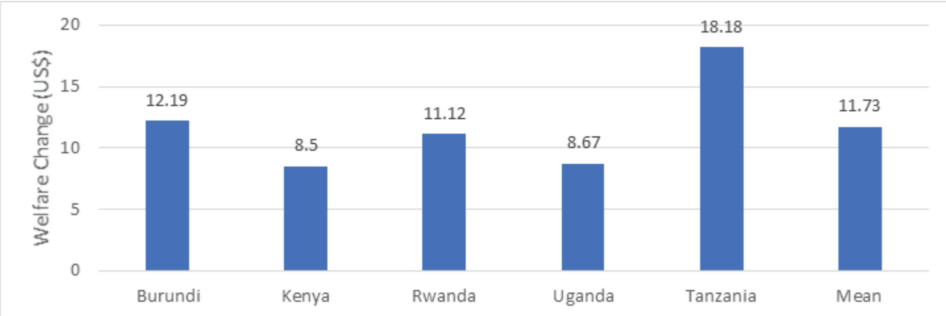
Table 16: Percentage change in price with Agricultural Policy in the mid-century

Crop	EAC Partner States				
	Burundi	**Kenya**	**Rwanda**	**Uganda**	**Tanzania**
Beans	-10.4	-15.7	2.9	-9.4	-32.1
Maize	-38.8	5.6	-3.7	0.8	-8.6
Millet	-54.6	-61.2	-72.9	-39.0	-56.2
Rice	-75.5	-59.4	-74.9	-64.0	-50.9
Sorghum	-71.3	-67.1	-54.2	-53.7	-84.9
Wheat	3.0	-6.1	-26.3	-18.6	-7.7

Source: Mulwa (2017)

The results show that with the implementation of this policy, there is a substantial percentage decline in prices in all countries compared to the baseline. This is because the policy boosts both demand and supply thus closing the deficit gap for most commodities. The welfare changes after the price changes is presented in Figure 31.

Figure 31: Per capita welfare change with implementation of agriculture policy



Source: Mulwa (2017)

As shown in the figure, the mean per capita welfare changes for the region (US$ 11.73) is higher compared to the baseline (US$ 7.93). Kenya has the lowest per capita income change of US$ 8.50, while Tanzania has the highest of US$ 18.18. This welfare change is higher than in the base model due to a 5% growth of grain production, a 3.5% per capita income combined with an increase in population growth. This finding is reaffirmed in grain trade flows shown in Table 17.

Overall, Tanzania will be the main exporter of beans, sorghum and wheat to Rwanda, Burundi and Kenya. On the other hand, Uganda will export Maize and Rice to Kenya and Rwanda. Kenya is a net importer of all commodities from EAC except wheat and millet.

Table 17: Intra-EAC trade flows with Agricultural Policy in the mid century

Commodity	EAC Partner States		
	Origin	**Destination**	**Quantity (000s) MT**
Beans	Tanzania	Burundi	154.17
Beans	Tanzania	Rwanda	1005.22
Maize	Burundi	Rwanda	220.40
Maize	Uganda	Kenya	1737.92
Millet	Kenya	Tanzania	62.65
Millet	Rwanda	Uganda	9.45

Rice	Burundi	Tanzania	107.32
Rice	Rwanda	Kenya	15.36
Rice	Rwanda	Tanzania	81.92
Rice	Uganda	Kenya	633.42
Sorghum	Tanzania	Burundi	133.11
Sorghum	Tanzania	Kenya	301.40
Sorghum	Tanzania	Rwanda	254.20
Wheat	Tanzania	Burundi	40.36

Source: Mulwa (2017)

Subsequently, EAC trade and RoW will change as shown in Table 18. From the analysis, Kenya, Rwanda and Uganda will import beans from the rest of the world, while all the countries except Burundi will supplement wheat imports from RoW.

Table 18: Grain trade flows with the rest of the world with Agricultural Policy

	Imports and Exports from RoW		
Commodity	**Origin**	**Destination**	**Quantity (000s) MT**
Beans	RoW	Kenya	2,393.72
Beans	RoW	Rwanda	217.43
Beans	RoW	Uganda	1,776.96
Wheat	RoW	Kenya	6,247.30
Wheat	RoW	Rwanda	289.34
Wheat	RoW	Uganda	1,449.83
Wheat	RoW	Tanzania	1,943.67

Source: Mulwa (2017)

5.3 Effect of agriculture and trade policies on Household welfare

To examine the effect of change in trade policy on household welfare, the EAC CET on grain commodities was doubled by mid-century and introduced into the model in section 5.2 (model with agricultural policy).

The results show that increased tariff will lead to higher commodity prices than the case with agricultural policy alone. This is because the trade policy will restrict international trade and narrow trade within the EAC region. In effect, this means that the purchasing power in the individual Partner States will be depressed as local production will not be enough to meet demand. Such a policy would suppress the gains made from adoption of the agricultural policy.

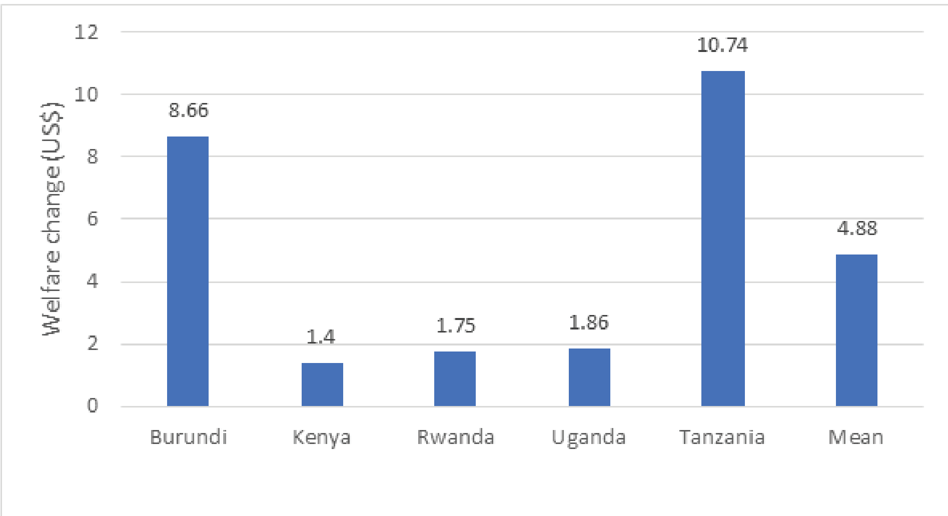
Table 19: Percentage price changes with trade and agricultural policies

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	19.60	24.60	40.50	36.40	-1.70
Maize	-38.80	5.60	-3.70	0.80	-8.60
Millet	-54.60	-32.20	-56.40	-31.40	-54.60
Rice	-58.70	-44.50	-54.10	-41.90	-43.30
Sorghum	-59.10	-52.80	-37.80	-40.90	-70.60
Wheat	42.80	43.30	3.00	30.90	34.40

Source: Mulwa (2017)

This indicates that increasing tariffs though meant to improve local production in the region end up hurting consumers and producers as the region is not yet self-sufficient and countries are forced to import. This adverse implication on the welfare are shown in Figure 32. Overall, the mean per capita welfare for the EAC declined to US$ 4.88, compared to per capital welfare in the previous scenario (US$ 11.73). With trade restrictions, per capita welfare for all the countries have also declined.

Figure 32: Per capita welfare change with implementation of agriculture and trade policies



Source: Mulwa (2017)

Trade patterns within the EAC will change with the combined effects of trade and agriculture policies as shown in Table 20. Tanzania will be a net exporter of most commodities. For example, it will export beans, maize, rice and wheat. Kenya will import maize from Uganda, and beans, sorghum and rice from Tanzania.

Table 20: Intra-EAC trade flows with trade and agricultural policies

Commodity	EAC Partner States		
	Origin	**Destination**	**Quantity (000s) MT**
Beans	Burundi	Rwanda	44.20
Beans	Tanzania	Kenya	960.01
Beans	Tanzania	Rwanda	751.40
Beans	Tanzania	Uganda	928.37
Maize	Burundi	Rwanda	220.40
Maize	Uganda	Kenya	1737.91
Rice	Burundi	Uganda	128.79
Rice	Tanzania	Kenya	623.77
Sorghum	Tanzania	Burundi	90.11
Sorghum	Tanzania	Kenya	190.00
Sorghum	Tanzania	Rwanda	200.20
Wheat	Tanzania	Burundi	34.13

Source: Mulwa (2017)

Trade between EAC countries and the rest of the world will also change as shown in Table 21. The revised tariff will increase the import prices and as a result no country will import any commodity from the international market. However, some countries will export millet, rice and sorghum.

Table 21: Grain trade flows with the rest of the world due to trade and agricultural policies

Commodity	Imports and Exports from RoW		
	Origin	**Destination**	**Quantity (000s) MT**
Millet	Kenya	RoW	119.59
Millet	Rwanda	Row	18.77
Millet	Uganda	Row	480.06
Rice	Rwanda	RoW	241.83
Rice	Uganda	Row	846.06
Rice	Tanzania	Row	702.99
Sorghum	Uganda	RoW	93.90
Sorghum	Tanzania	Row	685.46

Source: Mulwa (2017)

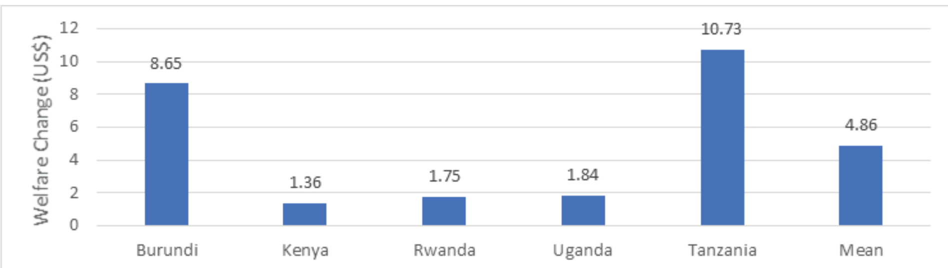
From the above analysis, whilst trade restriction are effective tools in restricting imports they may not necessary boost local production. Hence, they are likely to impact negatively on commodity prices and welfare.

5.4 Effect of agriculture and trade policies and climate change on household welfare

In this section, we examine the welfare effect after introducing climate change into the combined agriculture and trade policies model. The effects of climate change on area and yield are incorporated into the simulations through the intrinsic output growth rates obtained from the APSIM results (refer to Table 8). Note that in this study only maize production was simulated.

Changes in welfare after price change due to climate change, agriculture and trade policy are shown in Figure 33. The welfare changes are not significantly different from those without climate change as only one crop (maize) was considered. The gains vary for different countries but are slightly lower than in the scenario without climate change.

Figure 33: Per capita welfare changes with agricultural and trade policies and climate change



Source: Mulwa (2017)

The analysis in this chapter show that agriculture, trade policies and climate change affect will affect production and movement of food commodities in the EAC region by mid-century hence affecting the per capita welfare. The summary of these changes is shown in Table 22.

Table 22: Baseline, agricultural and trade policy and climate change per capita change in welfare in the mid century

	Baseline Welfare Change (US$)	Agricultural Policy Welfare Change (US$)	Trade and Agric Policy Welfare Change (US$)	Climate change, Trade and Agric Policy Welfare Change (US$)
Burundi	9.11	12.19	8.66	8.65
Kenya	6.06	8.50	1.40	1.36
Rwanda	7.62	11.12	1.75	1.75
Uganda	3.44	8.67	1.86	1.84
Tanzania	13.49	18.18	10.74	10.73
Mean	7.94	11.73	4.88	4.86

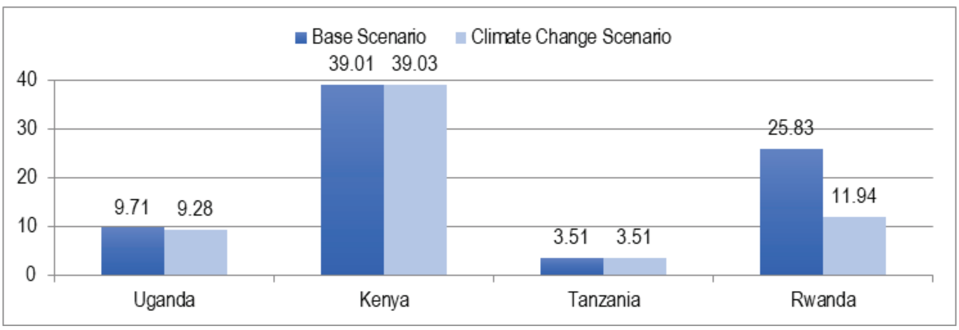
Source: Mulwa (2017)

From the baseline, the welfare effects in the region will be positive with increased investment in agriculture, but negative with trade restriction and climate change.

5.5 Impacts of climate change on food poverty

To further establish the effect of climate change on poverty, the Foster-Greer-Thorbecke (FGD) index was used. The impacts of climate change on private consumption were derived from Omolo (2017). The poverty line was adjusted to the food poverty line by estimating household expenditure on food. The number of households with expenditures below the food poverty line by county were identified to derive the poverty incidence. Figure 34 presents the results of food poverty incidence due to climate change.

Figure 34: Food Poverty Impacts



Source: Omolo, 2017

In Kenya, the base scenario food poverty incidence was 39.01 With a 0.04 per cent decrease in food consumption, food poverty incidence increased to 39.03 per cent. The reduction is attributed to the households' consumption basket, which comprise of 58 per cent of maize. Hence, any negative change in consumption will result in less of the food being available leading to household food insecure. Even though the percentage changes in food poverty incidences were found to be generally low, when the number of households is considered, the number shows a different picture. At the Base scenario, there were 3,316,314 poor households, but an additional 1,700 households become food poor with climate change.

In Tanzania, food poverty incidence was 3.51 per cent in the base scenario and remained unchanged when food consumption decreased to 2.05 per cent. This is because the most commonly consumed food items are: cereals, vegetables, and poultry were not affected by climate change, the effect associated by reduction in the production of maize, was not felt in the households even though 15 per cent of households consumed maize, due to substitution effects. At the base scenario, there were 326,430 poor households, with climate change, the number of poor households remain the same.

In Uganda, food poverty incidence was at 9.71 per cent, however, when food consumption decreased by 4.3 per cent in the climate change scenario, it reduced to 9.28 per cent. Conventionally, it is expected that when food consumption decreases, food security incidence goes up. However, in the case of Uganda, a decrease in consumption resulted in a decrease in food poverty incidence. There are many reasons for this. First, the decrease in food consumption affected non-poor households, secondly, commodities like sweet potatoes, which is mainly consumed by households recorded increases in production this improved the welfare of most households even though food consumption decreased in general. Lastly, information could have been lost between the social accounting matrix and the household survey data, the households are classified by rural, urban and farm and capital, while the households survey data classifies these households by quintiles. Matching these households could have resulted in some lost information. With climate change, the numbers of poor households reduce by 26,600 from the base number of 602,020 households.

Unlike most of the other EAC countries, Rwanda had positive results on food poverty incidence. The food poverty incidence reduced to 11.94 per cent following a 37 per cent increase in food consumption. One major challenge encountered with the Rwanda data is that the Social accounting matrix had all households lumped together. However, in the household survey data, the household were divided into quintiles. As a result, all households were assumed to bear the same impact of changes in food consumption, while in reality, different households classified by quintiles or location, rarely have unitary impacts associated with changes in food consumption. With an original number of 626,351 households being food poor, more than half the households (336,818) move out of food poverty.

6. Conclusions and Policy Recommendations

6.1 Conclusions

Agriculture is highly sensitive to climatic parameters and thus one of the sectors that is highly vulnerable to climate change. Combination of parameters simulated the maize crop phenology (flowering and maturity) very well for the calibration dataset.

The study shows that modification of the phenology parameters for maize resulted in comparability of actual yields (farmers estimate) and APSIM simulated yields. The analysis indicate that maize production is variable over different ACZ in the region during both the past and future. The projected climate change is expected to increase the gap in maize yield produced in the different ACZ in EAC. Climate change will result to decreased yield per hectare in some of the ACZ whereas in other ACZ, it will lead to increased maize yield. However, there exist other factors that are expected to influence crop production such as edaphic (soil), biotic, physiographic and socio-economic factors. Adaptation to climate change will be required in the future.

If status quo is maintained in macro-economic parameters such as income growth, production growth, and population increase, countries in EAC will be expected to improve their current welfare from key 5 grain crops by US$ 7.94 per person by the year 2045. This figure varies from country to country with the Tanzania, Burundi and Rwanda having the highest gains. Over the same period, grain trade within the EAC will be higher than with the rest of the world, although they will import beans, sorghum and wheat from out of the region. Prices for most grains in most of the countries will also decline. Introducing agricultural policy in the form of Malabo and Maputo declarations on the base scenario will boost welfare in all countries in the region and the mean welfare change will be US$ 11.73 per person with varying gains in the different countries. Grain prices will be depressed further down due to increased production and only beans and wheat will be imported into the region.

Increasing the CETs will depress trade with the rest of the world as imports will become very expensive. This will reduce the welfare in all the countries substantially as the mean welfare will reduce to US$ 4.88. This is an indication that though CETs were designed to protect local production, they will do more harm if they are increased. To avoid counter productiveness, they should be maintained at their current level or even reduced. Their impact is positive in grain trade as no single country imports grain from outside the region when CETs are increased.

Introducing climate change depresses the welfare further to a mean of US$ 4.86. Note that this is a light decline as only maize was considered in the analysis. Climate change therefore compounds the negative effects of increased CETs in the region. With increasing population, the regions demand for different food substances is expected to increase substantially in the coming years. This demand can be met by production and imports, hence the need to improve on quantities and numbers of different crops and livestock, respectively.

Uganda and Tanzania are the key exporters of maize and rice in the region, which are largely consumed by Kenya, Rwanda and Burundi. If the two suppliers are affected by any external factors that affect their maize production, then the region is likely to be food insecure. The policies set out by the EAC such as sanitary and phytosanitary (SPS), Standards and technical requirements and contingency measures affect agricultural commodities trade while the policies on agriculture affect agricultural production and food supply.

6.2 Policy Recommendations

Based on the analysis presented in this report, a number of recommendations can be drawn.

1. Policy reform: Mid-century projections indicate that with global warming up to a 4.5°C range, the region will benefit from increased precipitation and temperature ranges, implying that agricultural production could be enhanced. Therefore, the EAC partner states should consider adopting policies/strategies and programme which aim at building their adaptation capacity to utilise the weather conditions.

2. Enhance research and development: Through research, tolerant breeds and crop varieties can be developed, that can withstand the impacts of climate variability. At the same time countries should seek to identify their comparative advantages in production of various grains so that they can sell the surplus production and import commodities with deficits.

3. Increasing the level of public investments in the Agriculture sector is critical, countries made a commitment in Malabo to invest at least 10 per cent of their GDP in the sector. These investments will boost agricultural production in the region considering that population and incomes are continuing to grow.

4. There is need to remove trade restrictions and other forms of non-tariff barriers on EAC cross-border trade in order to boost supply and distribution of food products to deficit areas or regions.

5. Review the Common External Tariff (CET): Protection through high CET is counter-productive in the long-run and may not achieve the desired results especially since the region is not self-sufficient in grain production. The CET instead translates to higher market prices and encourages illicit trade in agricultural commodities in the region, hence reduce welfare.

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Appendices

Appendix 1: Climate change and crop model

Table A1: Agro-Climate Zones of EAC

	Burundi	Kenya	Tanzania	Rwanda	Uganda
1	Imbo plain;	Humid	Coastal	High land	North Eastern Drylands
2	west side of the Congo Nile Crest;	Sub-humid	Eastern plateau and mountain blocks	Central high plateau	North Eastern Savannah Grasslands
3	Congo Nile Crest;	Semi-humid	Southern highlands	Western high plateau	North Western Savannah Grasslands
4	Central Plateau and East	Semi-humid to semi-arid	Northern rift valley and volcanic high lands	Eastern plateau	Para Savannahs
5	North depressions	Semi-arid	Central plateau		
6		Arid	Rukwa-Ruaha rift zone		
7		Very Arid	Inland sedimentary plateau,		
8			Ufipa plateau		
9			western highlands		

Data and Methodology

Data Sources

Climate change and crop modelling data used included observed climate, climate model output, soil profile, key informant database and maize cultivar specific parameters

Observed Climate Data

Climate and crop modeling utilized daily observed data. These included Precipitation (PPT), Maximum Temperature (TMAX) and Minimum Temperature (TMIN) Model output were compared to observed datasets obtained from the National Meteorological and Hydrological service (NMHS) of Burundi (5 stations), Kenya (7 stations), Tanzania (7 stations), Rwanda (8 stations) and Uganda (10 stations) based on representative Agro-Climatic Zones. Moreover, solar radiation, required for crop modelling was estimated using the Hargreaves and Samani (1982, 1985) equation for each zone. Representative Agro-Climatic Zones were selected to evaluate the performance of the RCM models used as shown in Table A2.

Table A2: List of selected representative stations based on Agroclimatic zones

Uganda	Kenya	Tanzania	Rwanda	Burundi
Kotido/Kitgum	Kakamega	Dar Es Salaam	Gabiro	Bujumbura
Lira	Kisii	Dodoma	Kamembe	Nyanza Lac
Gulu	Eldoret	Arusha	Gisenyi	Gisozi
Masindi	Thika	Kigoma	Gikongoro	Muyinga
Soroti	Narok/Nakuru	Mbeya	Byumba	Musasa
Jinja	Garissa	Moshi	Save	
Kabale	Wajir	Morogoro	Ruhuha	
Masaka			Kigali	
Mbarara				
Kasese				

Regional Climate Model (RCM) data

In this study, simulated daily data used included rainfall, Maximum and Minimum temperature and sunshine duration data from 8 CORDEX RCMs. Nikulin et al. (2012) provide detailed information on the CORDEX models which include but not limited to model dynamics, physical parameterisation, its lateral and boundary conditions. Moreover, the output runs in the transient mode for the period 1951-2100. The eight (8) CORDEX models over the Africa domain are analysed for both historical (1971-2000) and future projections (2016 to 2045 and 2071 to 2100) based on RCP4.5 and 8.5 scenarios. All simulations performed are at 50km (0.448) resolution over the project domain. Table A3 presents a list of the eight (8) CORDEX models used.

Table A3: List of CMIP5 GCMs used in the study

Institute name	GCM name	Calendar
CCCma (Canada)	CanESM2	365 days
CNRM-CERFACS (France)	CNRM-CM5	standard
MOHC (UK)	HadGEM2-ES	360 days
NCC (Norway)	NorESMI-M	365 days
ICHEC (Europe)	Ec-EARTH	Standard

MIROC (Japan)	MIROC5	365 days
NOAA-GFDL (USA)	GFDL-ESM2M	365 days
MPI-M (Germany)	MPI-ESM-LR	standard

Data Limitations

EAC region lacks high-quality observation datasets at suitable temporal and spatial resolution necessary for evaluating RCM simulations. Therefore, the climate change modelling relied on post processed data available at CORDEX data portal. Endris et al. (2013) presents detailed limitations of CORDEX models for the Africa domain.

Downscaling of CORDEX Regional Climate

This study utilised dynamical downscaling techniques whereby, downscaled climate change models take data from GCMs and interpret them about local climate dynamics (Tadross et al., 2005). The period considered included both historical/past (1971 to 2000) and Future (2016 to 2045 as mid-century and 2071 to 2100 as end century). The future projections use Representative Concentration Pathways (RCPs) scenario 4.5wm2 and 8.5wm2. Dynamical downscaling makes use of RCM that are driven by a GCM to simulate regional climate. The ability of the RCMs to model atmospheric processes and land cover changes explicitly is regarded as its main advantage. However, RCMs may have limitations in simulating convective precipitation that is common in the tropics accurately.

Assessment of the skill of Climate models

The ability of the climate model to match the long-term historical climate observations was determined through both graphical and error analysis techniques. Error analysis techniques included Normalized root mean square error (NRMSE), Modified Nash-Sutcliffe Efficiency (mNSE) and Mean Absolute Error (MAE) techniques. RMSE evaluates the relative deviation between the simulation and the measurements in a range between 0 for a perfect match of simulation and measurement towards $+\infty$ indicating no match at all. Legates and McCabe (1999) present a detailed description of error analysis techniques. Notably, non-dimensional forms of the RMSE are useful because often one wants to compare RMSE with different units. Therefore, the study adopted the Normalized Root Mean Square Error (NRMSE). The Nash-Sutcliffe model efficiency coefficient (E) is commonly used to describe the accuracy of model outputs quantitatively. E ranges from - ¥ to 1 with values closer to 1 indicating model accuracy.

Determination of Trend of Past and Future Climate

This activity involved determination of spatial and temporal variability of past and future climate over EAC. The presence of a monotonic increasing or decreasing trend was tested with the nonparametric Mann-Kendall test while the slope of a linear trend was estimated with the nonparametric Sen's method (Gilbert 1987). Furthermore, the true slope of the existing trend (as change per year) was estimated using the Sen's nonparametric method.

Mann-Kendall test is a test that evaluates whether y values tend to increase or decrease over time through what is essentially a nonparametric form of monotonic trend regression analysis. To perform a Mann-Kendall test, compute the difference between the later-measured value and all earlier-measured values, (yj-yi), where j>i, and assign the integer value of 1, 0, or –1 to positive differences, no differences, and negative differences, respectively. The test statistic, S, is then computed as the sum of the integers:

$$s = \sum^{(n-1)}_{(i-1)} \sum^{n}_{(j=i+1)} sign\ (y_j - y_i) \text{ ....(1)}$$

Where $sign\ (y_j - y_i)$, is equal to +1, 0, or -1 as indicated above. When S is a large positive number, later-measured values tend to be larger than earlier values and an upward trend is indicated. When S is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of S is small, no trend is indicated. The test statistic τ can be computed as:

$$\tau = S/[n(n-1)/2] \text{ ....(2)}$$

which has a range of –1 to +1 and is analogous to the correlation coefficient in regression analysis. The null hypothesis of no trend is rejected when S and τ are significantly different from zero. If a significant trend is found, the rate of change can be calculated using the Sen slope estimator (Helsel and Hirsch 1992) given as

$$\beta_1 = median\ [(y_j - y_i)/(x_j - x_i)] \text{ ....(3)}$$

for all $i < j$ and $i = 1, 2, ..., n-1$ and $j = 2, 3,..., n$; in other words, computing the slope for all pairs of data that were used to compute S. The median of those slopes is the Sen slope estimator

The tested significance levels α are 0.001, 0.01, 0.05 and 0.1. A two-tailed test is used for four different significance levels α : 0.1, 0.05, 0.01 and 0.001. The significance level 0.001 means that there is a 0.1% probability that the values xi are from a random distribution and with that probability we make a mistake when rejecting H_o of no trend. Thus the significance level 0.001 means that the existence of a monotonic trend is very probable. Respectively the significance level 0.1 means that there is a 10% probability that we make a mistake when rejecting H_o.

For the four tested significance levels the symbols are used include *** if trend at $\alpha = 0.001$ level of significance, ** if trend at $\alpha = 0.01$ level of significance, * if trend at $\alpha = 0.05$ level of significance and + if trend at $\alpha = 0.1$ level of significance. If the cell is blank, the significance level is greater than 0.1. The true slope of an existing trend (as change per year) was estimated using the Sen's nonparametric method. The Sen slope was then expressed as percent of the mean quantity per unit time (Salmi et al., 2002; Slack et al., 2003). That is:

$$\%\ trend = [Sen\ Slope\ Estimator\ Q]/[mean\ f(year)]$$

Appendix 2: Spatial Equilibrium Model for Agricultural Policy Impact

To estimate the producer core system, we assume that the domestic crop production in the EAC region is determined by area and yield response functions, thus estimating acreage response only under-estimates supply response. This is because farmers in the region respond to price incentives partly through intensive application of other inputs given the same area, which is reflected in yield. This therefore requires an estimation of both acreage and yield response functions separately; and then deriving the supply response estimates from these two estimates. The supply response for the different crops was estimated using the Nerlove partial adjustment model Askari and Cummings, 1977; Leaver, 2004; Yu et al., 2010). The empirical model is given by;

$$lnC_{1t} = \delta_1 + \delta_2\, lnP_1\, C_{(1t\text{-}1)} + \delta_3\, lnC_{(1t\text{-}1)} + \delta_4\, lnP_2\, C_{(2t\text{-}1)} + \ldots, + \delta_n\, lnP_n\, C_{(nt\text{-}1)} + \gamma_1\, time + \mu_t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where C_{1t} is crop production at time; P_i is the price of crop i, while δ and γ are parameters to be estimated. The main and substitutable crops were jointly estimated by a single set of equations and by the introduction of other slope coefficients to capture different responses. For instance, in estimating the supply response for maize in Kenya, the independent variables were, one period lagged real price of maize, one period lagged maize output, one period lagged price of wheat, sorghum and millet prices, and a time variable to control for exogenous growth in maize output.

For the consumer core system, there are a number of factors that affect consumer food demand in the region. These are the price of the product; the price of related goods; the income of consumer; the preferences of consumers; and population. In our analysis, food demand was expressed as a function of the price of the commodity and the prices of other competing commodities, per capita income, and total population. The budget shares for the different commodities were estimated using proportions of food expenditure and per capita income. The budget shares for all grains have been calculated from the ratio of grain expenditure to total food expenditure and have been standardized to total to one. Own price and income elasticities of demand were estimated for using the Almost Ideal Demand System (Deaton and Muellbauer, 1980). The AIDS specification provides was used as the basis for an econometric estimation of the demand parameters. The empirical model of the AIDS demand model takes the form;

$$BS_{cr} = \alpha^D_{cr} + \sum^6_{(c'=1)} \beta^D_{cc'r}\, ln(PD_{c'r}) + \delta_{cr}\, ln(YR_r) + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where BS_{cr} is the budget share of commodity *c* in country *r*; α^D_{cr} is the intercept in the demand equation of *c* in country *r*; $\beta^D_{cc'r}$ is the coefficient on effect of price of *c'* on the demand of *c* in country *r*; PD_{cr} is the consumer price of commodity *c* in country *r*; and, YR_r is the nominal per capita income in country *r*.

The trade core system, domestic prices were expressed as a function of world prices, adjusted by the effect of price policies. With regard to the commodity balance equation, demand and supply are still equal to each other but they are defined more broadly to include international demand (exports) and international supply (imports). Using M_{in} for imports of commodity *i* in country *n* and X_{in} for exports of commodity *i* in country *n*, we can write the equation as;

$$QS^d_{in} + M_{in} = DF_{in} + X_{in} \text{ ....(3)}$$

The relationship between export price and domestic prices, can be expressed by setting the export parity price as the lower limit of domestic prices. Using price of exports p_{xin} as the FOB price, and NER_n as the nominal exchange rate, and TC_n as the transportation cost to the port country *n*: then, domestic price p_{din} of commodity in country can be expressed as;

$$p_{din} + TC_n \geq NER_n.p_{xin} \text{ ....(4)}$$

Similarly, import parity price sets the upper limit. If import p_{min} is the CIF price, then,

$$NER_n.p_{min} + TC_n \geq p_{din} \text{ ....(5)}$$

To analyze the impact of agricultural policies, trade policies and climate change on household welfare in the region, one can solve a competitive market equilibrium model with linear supply and linear demand functions using optimization method (e.g. maximization of net welfare) or the mixed complementarity problem (MCP) method. The impact is captured after introducing changes in exogenous variables of the model, which in turn influence the equilibrium price. Agricultural policies were introduced by changing demand and supply parameters in the demand and supply core blocks. Trade policy was introduced by changing import and export prices. Climate change was introduced in to the supply side of the equation. Its effects on area and yield are incorporated into the simulations through the intrinsic output growth rates (*gQ*) as shown in equation in the supply block equations.

$$lnS_{cr} = \alpha^S_{cr} + \sum^6_{(c'=1)} \beta^S_{cc'r} \ln(PS_{c'r}) + (1 + gQ + E^Q_{Clim}) \text{ ....(6a)}$$

The average annual rate of growth or decline of output due to climate change is then added to the existing exogenous output growth rate. In this case gQ is expressed as;

$$gQ = gQ_{WC} + E^{Q}{}_{Clim} \text{ ....(6b)}$$

Where lnS_{cr} is the log of crop output under climate change; gQ_{WC} is the intrinsic output growth rate without climate change, while $E^{Q}{}_{Clim}$ are the effects of climate change on output growth rate. Having incorporated natural growth only, we introduce climate change into the equation. Note that in this study only maize production was simulated for climate change using APSIM model both for RCP 4.5 and RCP 8.5. The RCP 4.5 assumes a lower carbon dioxide in the atmosphere, while that of RCP 8.5 is higher.

The changes in exogenous variables influences the equilibrium price. This change in price is then used in estimating the change in welfare to consumers and producers. Compensating variation (Minot and Goletti, 2000) was used as a measure of consumer price changes and is given as;

$$CV/x_o \approx CR_{cr} [(\Delta p_{cr})/(p_{ocr})] + 1/2\ \varepsilon^{H}{}_{cr}\ CR_{cr} [(\Delta p_{cr})/(p_{ocr})]^2 \text{ ....(7)}$$

Where, CR_{cr} is the consumption ratio of commodity *c* sold in country *r* (i.e. value of consumption of *c* sold in country *r* as a proportion of income (total expenditure); Δp_{cr} is the change in price; p_{ocr} is the original price; and $\varepsilon^{H}{}_{cr}$ is the Hicksian own-price elasticity of demand commodity *c* sold in country *r*. The effect on producer prices is given by;

$$\Delta x/x_o \approx PR_{cr} [(\Delta p_{cr})/(p_{ocr})] + 1/2\ \varepsilon^{S}{}_{cr}\ PR_{cr} [(\Delta p_{cr})/(p_{ocr})]^2 \text{ ....(8)}$$

Where, Δx is the change in income; x_o is the original income; PR_{cr} is the production ratio of commodity *c* in country *r* (i.e. value of production of commodity *c* sold in country *r* as a proportion of income (total expenditure); and $\varepsilon^{S}{}_{cr}$ is the own supply elasticity of commodity *c* sold in country *r*.

If we combine the producer welfare (impact of price changes on farming households) and consumer welfare (impact of retail prices on consuming households) equations, we obtain;

$$(\Delta w^2)/x_o = (\Delta p'_{cr})/(p'_{ocr})\ PR_{cr} + 1/2\ [(\Delta p'_{cr})/(p'_{ocr})]^2\ PR_{cr}\ \varepsilon^{S}{}_{cr} - (\Delta p_{cr})/(p_{ocr})\ CR_{cr} + 1/2\ [(\Delta p_{cr})/p_{ocr})]^2\ CR_{cr}\ \varepsilon^{H}{}_{cr} \text{ ....(9)}$$

Where, Δw^2 is the second order approximation of net welfare effect of a price change in commodity *c* in country *r* on households, where *p'* and *p* distinguish producer and consumer prices, respectively. The immediate welfare impact - without consumer and producer responses - can be obtained by setting the elasticities equal to zero to obtain;

$$(\Delta w^1)/x_o = (\Delta p'_{cr})/(p'_{ocr})\ PR_{cr} - (\Delta p_{cr})/(p_{ocr})\ CR_{cr} \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Where, w^1 is the first order approximation of net welfare effect of a price change. This is the welfare impact of a price change assuming that the consumer cannot respond to the change by adjusting consumption. Geometrically, it is a rectangular approximation of the area behind the curve. The second order approximation, w^2, takes into account the response of consumers to the higher price. It is a parallelogram approximation of consumer surplus. It is an approximation because it assumes the demand curve is linear (Goletti and Minot, 1999).

Changes in commodity prices will influence trade flows within the EAC, but also with other countries out of the EAC. From the models we obtained the trade flows for the different grain crops within EAC and also with the rest of the world.

Appendix 3: MCP Model

This section gives a description and the equations used in the MCP of the SEM. They are classified into endogenous variables and parameters. The model considers 6 crops (maize, beans, sorghum, millet, rice and wheat), which are considered as the main agricultural crops traded in the EAC. The 5 region-6 crop SEM model comprises of four blocks of equations: prices, supply, consumption and market clearing identities for the six crops. The General Algebraic Modelling Systems (GAMS) package was used to solve the equations. Tables A4 and A5 show the model variables and parameters used in estimation.

Table A4: Endogenous variables of the model

Symbol	Endogenous variable
BS_{cr}	Budget share of commodity *c* in country *r*
S_{cr}	Supply of commodity *c* in country *r*
PS_{cr}	Producer price of commodity *c* in country *r*
PD_{cr}	Consumer price of commodity *c* in country *r*
M_{cr}	Imports of commodity *c* in country *r*
X_{cr}	Exports of commodity *c* in country *r*
PX_{cr}	Export price of commodity *c* in country *r*
$TQ_{crr'}$	Quantities of commodity *c* transported from country *r* to *r'*
YR_{r}	Nominal per capita income in country *r*
IXT_{c}	Implicit export tax associated with quota on commodity *c*

Table A5: Parameters of the model

Symbol	Parameter
$\alpha^{S}{}_{cr}$	Intercept in the supply equation of *c* in country *r*
$\beta^{S}{}_{cc'r}$	Coefficient on effect of price of *c'* on the supply of crop *c* in country *r*
$\alpha^{D}{}_{cr}$	Intercept in the demand equation of *c* in country *r*
$\beta^{D}{}_{cc'r}$	Coefficient on effect of price of *c'* on the demand of *c* in country *r*
δ_{cr}	Coefficient on effect of price income on the demand of *c* in country *r*
$Y^{o}{}_{r}$	Original per capita income in country *r*
$PP^{o}{}_{cr}$	Original price for valuing output of commodity *c* in country *r*
POP_{r}	Population in country *r*
$TP_{rr'}$	Transportation cost from country *r* to country *r'*
$ITX_{crr'}$	Implicit tax on regional transportation of *c* from country *r* to country *r'*
PM_{c}	Import (c.i.f) price of commodity *c* in country *r*
Q_{c}	Export quota on price of commodity *c* in country *r*
$E^{Q}{}_{Clim}$	Climate change impact on maize production

Specification of Supply

$$lnS_{cr} = \alpha^{S}_{cr} + \sum^{6}_{(c'=1)} \beta^{S}_{cc'r} \, ln(PS_{c'r}) + (1 + gQ + E^{Q}_{Clim}) \text{ ....}(a)$$

Specification of Demand

$$BS_{cr} = \alpha^{D}_{cr} + \sum^{6}_{(c'=1)} \beta^{D}_{cc'r} \, ln(PD_{c'r}) + \delta_{cr} \, ln(YR_{r}) \text{ ....}(b)$$

Outflows from country

$$S_{cr} \geq \sum^{6}_{(r'=1)} TQ_{(rr')} + X_{cr} \text{ ....}(c)$$

Inflows to country

$$\sum^{6}_{(r'=1)} TQ_{(rr')} + M_{cr} \geq [(BS_{cr} \, Y_{r})/(PD_{cr})] \, POP_{r} \text{ ....}(d)$$

Regional price relations

$$PS_{cr} + TP_{rr'} + ITX_{rr'} \geq PD_{cr} \text{ ....}(e)$$

Import-Regional price relations

$$PM_{cr} + TP_{(world\ r)} + ITX_{(world\ r)} \geq PD_{cr} \text{ ....}(f)$$

Export-Regional price relations

$$PS_{cr} + TP_{(world\ r)} + ITX_{(world\ r)} + ITX_{c} \geq PX_{r} \text{ ....}(g)$$

Export quota

$$\sum^{6}_{(r=1)} X_{cr} \leq Q_{c} \text{ ....}(h)$$

Appendix 4: Supply Data

The data considered in the production core equation is the supply (production) of the different crops. For this analysis, we considered the average production of 8 years, i.e. the period between the years 2006-2013 as the base grain production (Table A6). The largest producer of Maize, Rice and Sorghum is Tanzania while Kenya leads in Wheat production.

Table A6: Grain Production in EAC in 000s MT

Crop	EAC Partner States				
	Burundi	**Kenya**	**Rwanda**	**Uganda**	**Tanzania**
Beans	210.54	573.61	400.75	444.61	996.25
Maize	174.65	3204.00	544.50	1683.84	5607.85
Millet	11.00	70.00	9.00	820.00	350.00
Rice	67.00	130.00	82.00	230.00	980.00
Sorghum	70.56	132.93	157.49	420.00	840.00
Wheat	9.00	247.00	81.00	24.00	93.00

Source: FAO, 2015

The producer price data considered for the base period was also an average of 3 years from year 2013-2015. These are shown in Table A7 and vary for the different crops in the five countries. Overall beans have the highest price per metric ton while maize and millet prices are the least.

Table A7: Producer prices in US$/MT in EAC

Crop	EAC Partner States				
	Burundi	**Kenya**	**Rwanda**	**Uganda**	**Tanzania**
Beans	550	620	590	560	520
Maize	158	257	230	167	185
Millet	139	364	165	180	231
Rice	267	234	336	240	284
Sorghum	211	251	298	205	211
Wheat	393	350	380	330	325

Source: FAO, 2015

The grain production and grain supply prices in Tables A6 and A7 were used in estimating supply response using equation 1.

Appendix 5: Demand Data

The data considered in the demand core equation are the consumer prices (Table A8) and consumption demand (Table A9) of the different crops. These data were for the period 2014 and 2015. From Table 3, the highest prices are reported for beans and rice in almost all countries in EAC. Data from Table 4 shows that the largest consumers of maize are Tanzania and Kenya; rice is Tanzania; and wheat is Kenya.

Table A8: Consumer prices in US$/Ton in EAC

Crop	EAC Partner States				
	Burundi	**Kenya**	**Rwanda**	**Uganda**	**Tanzania**
Beans	690	682	630	660	778
Maize	445	320	345	257	280
Millet	682	550	688	510	682
Rice	954	950	968	850	780
Sorghum	570	483	423	330	487
Wheat	563	442	662	538	531

Source: EAGC, 2015; FEWSNET 2014

Table A9: Consumer Demand in Tons in EAC

Crop	EAC Partner States				
	Burundi	**Kenya**	**Rwanda**	**Uganda**	**Tanzania**
Beans	224.46	900.00	700.00	690.00	708.25
Maize	169.46	3450.00	564.07	1308.79	4670.49
Millet	9.83	62.90	9.00	720.00	239.33
Rice	58.00	370.00	83.00	187.00	1176.00
Sorghum	73.67	128.75	155.00	325.00	697.42
Wheat	19.50	900.00	195.00	390.00	980.00

Source: FAO, 2015; Other Online sources

Using the populations in respective countries and the consumption demand in Table A10, we estimated the annual per capita consumption of the different commodities in Kgs (Table A11). Rwanda has the highest consumption of beans per capita (64.6Kg), while Kenya has the highest per capita consumption of Wheat (47.67Kg). Tanzania has the highest per capita consumption of maize (94.83kg), while Uganda has the highest per capita consumption of millet (19.81kg).

Table A10: Consumption in Kgs/Person per year

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	26.95	22.00	64.59	18.98	14.38
Maize	20.35	84.33	52.05	36.01	94.83
Millet	1.18	1.54	0.83	19.81	4.86
Rice	6.96	9.04	4.87	5.14	23.88
Sorghum	8.85	3.15	14.30	8.94	14.16
Wheat	2.34	47.67	17.99	10.73	19.90

Source: Author's estimation

The consumption levels presented in Table A11 require budgets from households' total income, per capita income, total food expenditure, and expenditure of the six grain crops in the different EAC countries are shown in Table A6. Kenya had the highest per capita income (US$ 1,100) while Burundi has the least (US$ 217). Expenditure on grains is also shown with Kenya leading on the total expenditure allocated to grains (US$ 105.90) followed by Tanzania (US$ 77.14) and Rwanda (US$ 72.49). However, as a percentage of the total food expenditure, Rwanda allocates 21.58% while Uganda allocates the least (15.04%).

Table A11: Per capita income, Food and Grains Expenditure (US$)

Income/Exp.	Burundi	Kenya	Rwanda	Uganda	Tanzania
Per capita income	256.00	1100.00	660.00	661.40	813.00
Food Exp.	146.18	542.96	335.94	308.21	422.86
Grains Exp.	41.46	105.90	72.49	46.34	77.14
% Grain: Food Exp.	28.36%	19.50%	21.58%	15.04%	18.24%

Source: EAC, 2013 and Author's estimation

Using information in previous demand Tables, the budget shares for the different commodities were estimated using proportions of food expenditure and per capita income. For example, on average, Burundi uses 21.84 % of the total grain expenditure on maize; 1.94% on millet, 44.85% on beans etc. Kenya spends 36.46% of all grain expenditure on Maize, 20.27% on beans, and the rest on the others. Tanzania spends the biggest proportion of grain expenditure on maize (34.42%) and 24.14% on rice (Table 5).

Table A12: Budget shares of grains in EAC

Crop	EAC Partner States				
	Burundi	Kenya	Rwanda	Uganda	Tanzania
Beans	0.4485	0.2027	0.4969	0.2785	0.1450
Maize	0.2184	0.3646	0.2193	0.2057	0.3442
Millet	0.0194	0.0114	0.0070	0.2246	0.0430
Rice	0.1602	0.1161	0.0575	0.0972	0.2414
Sorghum	0.1216	0.0205	0.0739	0.0656	0.0894
Wheat	0.0318	0.2846	0.1455	0.1283	0.1370

Source: Author's estimation

The demand and price data in Table 1 to 5 were used to estimate own price and income elasticities of demand for the domestic demand equation using the AIDS model in Equation 2.

Appendix 6: Trade Policies Affecting Agriculture Trade at the EAC

Trade Policies	Features
Customs Procedures and Documentation	• Addressed in the Customs Management Act • The objective is to standardize and harmonize the customs formalities (documentation and procedure) in the member states • Customs Procedures Manual was adopted by EAC council of ministers and application commenced in 2012/13
Customs Valuation	• Procedure applied to assign monetary value to goods or service for the purposes of import or exports. • Incorporated in the EAC Customs Management Act, 2004 • Based on the implementation of the WTO Agreement on the implementation of Article VII of GATT 1994 on customs valuation

Tariffs and Other duties	• MFM Applied Tariff structure
	  • EAC Common External Tariff (CET)-
	    • Raw materials and capital goods are zero-rated.
	    • Intermediate goods is 10%
	    • Finished goods 25%
	    • Sensitive products apply 35-100%, this apply to 58 tariff lines
	  • CET Contains 5,274 lines at HS8-digit level. 99.8 % carry ad valorem while the rest have mixed tariffs

Tariff Preferences	• EAC members can grant tariff preferences on reciprocal basis under bilateral agreements.
Tariff and tax exemptions and concessions	• Under customs union protocol, members have agreed to harmonize their duty and tax exemptions and concessions. • The EAC Council on a case-by-case basis also grants country specific waivers.
Internal Taxes	• Under EAC Common Market Protocol, members have agreed to harmonize their tax policies and laws on domestic taxes. • This will remove tax distortion and facilitate free movement of goods, services and capital in order to promote investment in the community.
Contingency Measures	• Contingency Measures found in Article 16-20 and 24 on the Protocol Establishing the EAC customs union. • These contingencies include anti-dumping, countervailing and safeguards measure.
Import Prohibitions, restrictions and licensing	• Provided under the Second Schedule of the EAC Customs Management Act, 2004. • EAC member states have a schedule of prohibited products. • Import permit is required for 31 product groups under the second schedule.
Standards and Technical Requirements	• Article 13 on Protocol Establishing the EA Customs union urges removal of non-tariff barriers (NTBs). • Catalogue of East African Standards provides a comprehensive list of harmonized standards applicable to EAC.
Documentation taxation and restrictions	• These documentation requirements for exports. • Addressed in the Customs Management Act

Competition and Regulatory Issues	• Article 21 of Customs Union Protocol obliges EAC member states to prohibit anti-competitive behaviors. • EAC Competition Act was enacted in 2006 and established the EAC Competition Authority.
Intellectual Property Rights	• Addressed in Article 103 of the EAC Treaty and Art. 104 of the EAC Common Market Protocol • This sets up the framework for the harmonization of EAC intellectual Property Rights Policies.
Agriculture	• The treaty establishing the EAC emphasized the importance of agriculture and food security, and made it a key cooperation area. • Several regional policies have been developed: • Agriculture and Rural Development Policy • Agriculture Rural Development Strategy • EAC Food Security Action Plan • Regional Protocol on Environment and Natural Resource Management (2006).

Source: Authors Compilation from WTO EAC Policy Review (2012)

Appendix 7: The Computable General Equilibrium (CGE) Model

CGE models provide an analytical approach that views the economy as a system of interdependent sectors of the economy. In this framework, economic shock emanating from one sector creates ripples in other sectors, secondly, it is possible to undertake quantitative analysis by solving the general equilibrium numerically, hence one can undertake economy wide analysis at global or even regional level. The CGE model can handle a broad spectrum of issues such as taxation, trade, pollution, welfare etc., it is equally possible to establish forward and backward linkages between sectors. This model is therefore appropriate for establishing the climate change, agricultural production and trade impacts on food security, this is because the model will be able to simulate the functioning of the economy under certain climatic conditions which affect productivity and total production. These effects are transmitted through price and quantity adjustments in the various markets, secondly, given that a CGE is based on a social accounting matrix, it will be possible to establish the effects of climate change on different sectors of the economy, linking the model to household survey enables an in depth assessment of household welfare effects due to climate change, it is from here that the policy implications are drawn. It should be noted that this is a static equilibrium model which seeks to establish the effects of climate change on production, trade and household welfare at a given point in time. The time here is based on data sources as explained in section 4.4.3.

The CGE model will follow the works of Löfgren et al. (2001). There are four blocks of equations: prices, production and trade, institutions and the systems constraints block. Calibration of the model will be based on working by Lofgren et al. (2002). In the CGE model, there are parameters, variables and equations that are defined. In this paper, the key equations that are affected by climate change are presented and discussed. It is important to show the structure of production and how it is affected by changes in yield.

ISBN 9966 817 13 6

Kenya Institute for Public Policy Research and Analysis
Bishops Garden Towers, Bishops Road
P.O. Box 56445-200, Nairobi, Kenya
Tel: +254 20 2719933/4, 2714714/5, 2721654, 2721110
admin@kippra.or.ke

African Climate Policy Center
UN Economic Commission for Africa
Menelik II Ave.
P.O. Box 3001, Addis Ababa, Ethiopia
Tel: +251 11 544 5000
acpc@un.org