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Adaptation and Mitigation Options and the Economy-wide Effects of Climate Change in Uganda: An Application of a Dynamic CGE Model

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Abstract

Although Uganda's emissions are relatively low compared to industrialised economies, the country is among the most vulnerable to extreme climate change events like floods and droughts. The effects of these events have immediate impacts on economic growth given that the economy's agriculture is rainfed and contributes about a quarter of economic activity (GDP) and employs more than half the population. This paper uses a Computable General Equilibrium (CGE) model to investigate the fiscal policy options of adaptation and mitigation to cushion the economy against the effects of climate change. The findings provide insights into the effectiveness of combining adaptation and mitigation measures in achieving long-term sustainability and resilience to climate change. First, we found that greenhouse gas (GHG) emissions in Uganda are generated by sectors accounting for a quarter of economic output. In addition, the results show that adoption of carbon tax mitigation measures reduces GHG emissions from economic activities, whereas building climate-resilient infrastructure reduces the impact of climate change hazards on macroeconomic outcomes. Worth noting, the carbon tax comes along with economic costs of minor reduction in economic growth, which cumulatively can dampen growth in the long-term. Thus, to cushion the effects of carbon tax measures on growth; the policy should be followed by using the proceeds to invest in capital accumulation, especially the construction of climate-resilient infrastructure. This shows that an effective climate policy would require complementarities between adaptation and mitigation rather than treating them as mutually exclusive policies. Based on the above results we recommend the government designs enforceable climate policies at national level, like carbon pricing mechanisms and emissions reduction targets, which would implicitly ensure the alignment of sectoral policies with climate goals. To expedite the contribution to the attainment of the National Determined Contributions (NDCs); the carbon tax and investment in resilient infrastructure should be complemented with a transition to renewable energy sources such as solar, wind, and hydroelectric power.

Keywords: Fiscal policy, climate change, Uganda.

JEL classification: C68, Q54, H23, H54, H30.

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At the heart of RAMP's approach to capacity-building is its University Network for Strengthening Macrofinancial Resilience to Climate and Environmental Change ('the RAMP University Network'). Launched in 2022, the RAMP University Network consists of leading universities in vulnerable countries that seek to develop and deliver high-quality multi-disciplinary teaching and research on adaptation economics and climate risk management, train public officials, and serve as centres of expertise that ministries of finance and other public institutions can rely on. This approach ensures that skills and knowledge are embedded locally, strengthening partner countries' ability to integrate climate risks into economic decision-making.

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1. Introduction

The global economy has grappled with the retarding effects of climate change, which has seen the destruction of public infrastructure, loss in outputs, and reduced productivity of labour in the production process (Craighead, 2017 and USAID, 2012). In the case of Uganda, the country has enjoyed dividends of macroeconomic stability and growth, but these achievements have been affected by increasing frequency of climate change-related disasters like floods, droughts and landslides.

In addition, more than half of Uganda's labour force has remained trapped in the agriculture sector producing a quarter of the GDP (World Bank, 2022). The agriculture sector is overstretched, and for the last decade has sustained stalled labour productivity and remains highly susceptible to climate change effects and increased unpredictability of rainfall (World Bank, 2022). In the last five years, the government budget has increased expenditure on social transfers to support households affected by climate-related disasters. For example, allocating more financial resources to the reconstruction of public infrastructure like roads washed away by floods and mudslides. These additional fiscal costs, together with external shocks like COVID-19 and the Ukraine-Russia conflict, have stretched the government budget to a fiscal deficit of 7.4% of GDP in FY 2021/22 – far higher than the 3% target set by the East African Community (EAC) member states (MoFPED, 2022).

The above fiscal developments constrain the government's ability to provide adequate public services and create jobs for the rapidly growing population. This has left environmental resources as the default source of livelihood for the majority of Ugandans, thus leading to depletion. NPA (2020) shows that about 120,000 hectares of forest cover is lost annually in Uganda as a result of increased human activity – specifically charcoal burning and firewood collection.

Despite the above developments, there is hardly any literature on Uganda regarding the modelling of climate change mitigation and adaptation. We propose to use the Computable General Equilibrium (CGE) model to capture the economy-wide and sectoral impacts of climate change. Damage functions will be included in the customised CGE model to capture and profile the impact channels of climate change on output (especially agriculture), labour productivity, and the damages to the stock of infrastructure induced by climate natural hazards, such as floods or droughts.

The specific research questions are:

i. What are the economy-wide impacts of climate change related hazards like floods on the Ugandan economy? This will support in formulating empirical teaching materials for macroeconomic modelling and policy of climate change.

ii. Using the damage function, what is the contribution of climate-resilient infrastructure in reducing the damaging effects of adverse climate change events like floods? [*This provides a baseline for teaching materials on incorporating damage functions, and fiscal policy effects and response, using economy-wide models (CGE)].*

iii. What is the theoretical basis that explains the effects of climate change on output, labour productivity, and infrastructure?

iv. How effective is carbon tax in mitigating climate change in terms of emission reduction? Are there feedback effects of such policies?

The following sections are arranged as follows. The next section discusses the literature, followed by section 3.0 which discusses the theoretical framework, and section 4.0 that covers methodology. Thereafter, we proceed to section 5.0 which discusses the results, and we close with section 6 which provides the conclusion and recommendations.

2. Literature review

Climate change is one of the most pressing challenges facing humanity today, with significant implications for ecosystems, societies, and economies worldwide. The Intergovernmental Panel on Climate Change (IPCC) has highlighted the urgent need for both adaptation and mitigation strategies to address the impacts of climate change and limit future warming.

Adaptation involves adjusting to the current and anticipated effects of climate change, such as rising sea levels, changing precipitation patterns, and extreme weather events, to reduce vulnerability and enhance resilience. Mitigation, on the other hand, focuses on reducing greenhouse gas emissions and enhancing carbon sequestration to slow the pace of global warming. In recent years, there has been a growing body of research on the effectiveness of various adaptation and mitigation measures, as well as the social, economic, and political challenges associated with their implementation. This literature review examines the current state of research on these strategies, exploring their potential and limitations in addressing climate change. In addition, the literature shows the existence of unique and differentiated impacts of climate change on different countries and sectors (Chateau, 2021).

Regarding economic tools for climate change analysis, literature is marred with a continuum of economic tools that can be used. The majority of them are economy-wide tools like Computable General Equilibrium (CGE) models followed by Econometric tools. Scholars like Chateau (2021) emphasise the need to use economy-wide modelling tools in assessing the policy implications of climate change. The paper used a CGE model to assess climate change mitigation and its economic implications. Part of the findings link climate change to losses in labour productivity, loss in agricultural crop yields, land loss in case of rise in water/sea level and adjustments in energy demand. This shows the existence of the disproportionate effects of climate change on labour productivity, and general output productivity. This suggests that as we simulate climate change in this paper, it is of paramount importance to observe the shock incidence regarding total factor productivity.

Regarding the incorporation of adaptation economic models, scholars have modelled economic resilience through reducing the rate to the capital depreciation rates, whereas others have focused on investment in irrigation, drought-tolerant crop species and many more. Scholars like Forni *et al*. (2018) used an overlapping generation (OLG) model to assess the effects of increasing resilience infrastructural capital as a fiscal policy for climate adaptation. Thus, adaptation in this essence is captured by public policies that reduce the climate change effects on the depreciation rate of capital.

The paper describes adaptation as having two faces; first the preventive measures like investing in climate resilient infrastructure, and secondly the remedial measures which focus on the aftermath of the climate change event, or post-disaster policies like relief and reconstruction of damaged infrastructure. The paper concludes that the preventive fiscal policy measures lead to higher GDP compared to the scenario of waiting for the remedial policies. The paper also notes that higher costs of preventive measures have pushed economies to sub-optimal fiscal remedial measures. This, coupled with budgetary constraints means corrective actions are then left to international assistance. The paper recommends the design of a comprehensive strategy that covers preventive and corrective actions to strengthen resilience to climate-related shocks, especially in small countries.

In the same area, Aaheim (2022) used a CGE model to analyse climate change adaptation. The review covered 170 articles and found that CGE models are instrumental in assessing climate change adaptation and can support a detailed economy-wide assessment. The papers reviewed, focussed on autonomous adaptation whereas others focussed on planned adaptation, with the agriculture sector the most explored in the research articles. The findings also show that autonomous adaptation was found to be key in mitigating direct climate change impacts, although they recommend further studies in the same area. Based on their findings, the paper strongly recommends the use of CGE models in providing an assessment of adaptation and mitigation measures.

Within Africa, CGE models are also increasingly being used for climate change analysis. Scholars like Sawadogo (2022) used a gender-focused CGE model to assess the impacts of drought on the crop sector adaptation options in Burkina Faso. The findings of the paper show that intensive drought has the potential to constrain growth to a tune of 3.0% in the short term and 3.3% in the long term; and on socio-economic welfare, women were found to bear the heaviest brunt of droughts. The paper recommends the adoption of drought-tolerant crops, irrigation and integrated soil.

Arndt *et al.* (2011) used a dynamic CGE model to study Ethiopia's growth prospects in a changing climate, with a focus on adaptation policies. They found that aggregate consumption has higher variability than other macro aggregates in the event of adverse climate change events. Thus, they conclude that the burden of climate change falls more on consumers in the economy, especially the poor. In addition, Gebreegziabher *et al.* (2016) also used the CGE model for Ethiopia to study the effects of climate change on the Ethiopian economy, with the main focus on the agricultural sector. The paper found that a reduction of agricultural productivity due to climate change over 50 years would reduce the average income for Ethiopia by 20%. This shows the existence of a negative relationship between income and climate change. The paper recommends the adoption of adaptation policies to discount these effects.

Within the East African Community, Mulwa (2017) found that the East African Community is highly vulnerable to climate change; and is experiencing damaging climate change events like extreme weather conditions of drought, floods, and landslides which are threatening food security and compromising government efforts to eradicate poverty. The paper uses a regional spatial Equilibrium Model on the EAC economies and found out that welfare losses due to climate change shock were higher in Rwanda, followed by Kenya, Tanzania, Uganda and lastly Burundi. This shows that there are welfare gains in Uganda and the rest of the EAC region when actionable mitigation and adaptation measures are adopted

In addition to climate change analysis within the EAC region, Laibuni *et al.* (2019) used a spatial equilibrium model (SEM) to assess the effects of climate change on agricultural production, trade, food security and welfare in the East African Community. Their findings show that climate change reduces agricultural production and food security as well as trade and welfare. Specifically, the paper identifies Uganda and Tanzania as the leading producers of the main agricultural food (maize) which they export to Kenya, Rwanda and Burundi. Thus, if drought or floods affect the productivity of maize in Uganda and Kenya, it would deteriorate the food security of the whole East African Community. This shows that the effect of climate change on Uganda's output extends beyond Uganda and spills over to the rest of the East African Community. In addition, Willenbockel (2019) used an exploratory Dynamic General Equilibrium Analysis to assess the macroeconomic effects of transitioning to low-carbon electricity in Kenya and Ghana. The findings show the feasibility of transitioning to low-carbon electricity without adverse economic effects on growth, and the related distributional effects.

In the case of Uganda, Matovu (2013) used a panel data analysis technique and a Dynamic CGE model for Uganda to assess the effects of climate change on productivity, growth and welfare Effects. The paper found differentiated effects of climate change (temperature and precipitation) on the productivity of crops. The paper shows that erratic rainfalls and changing temperatures have negative impacts on crop productivity. However, rainfall levels were not found to have significant effects on crop yield. The paper concludes that, in the case of Uganda, climate change would take about 30 years to have a significant impact on the economy. However, this conclusion of the paper is based on rainfall and temperature, but not extreme weather events like floods and drought. UN (2020) and KCCA (2019) show that the frequency of floods in Uganda has increased. In addition, the Budget Monitoring and Accountability Unit (BAMU) of the Ministry of Finance, Planning and Economic Development (MoFEPD) shows that in 2017/18 drought divested the crop harvest in Uganda, quoting a case of a farmer whose harvest was reduced from 200 bags of potatoes to only 10 bags due to drought (BMAU, 2018). *Ibid* also shows that in the same period, sugar cane production reduced by 10.6% due to drought. This shows that Uganda is vulnerable to adverse weather shocks in the short and medium term as opposed to the long-term proposition by Matovu (2013). Also, BAMU (2019) shows increasing cases of flooding in the previous cattle corridors in Uganda. These adverse weather events risk the sustainability of Uganda's economic growth, given that about a quarter of GDP is attributed to agriculture. Therefore, an economy-wide study on climate change adaptation options to reduce vulnerabilities in Uganda is needed.

In addition, other modelling approaches have been used for climate change analysis in Uganda. For instance, Sebukeera *et al.* (2023) used a Vector Error Correction (VECM) and Johansen Cointegration Econometric Analysis to assess the effects of climate change variability on economic growth in Uganda. The paper identifies that Uganda's macroeconomic modelling framework falls short of modelling climate change. The paper found positive feedback to agriculture and industry, and negative to services in the scenario of climate change (precipitation). Climate change (temperature) was found to have positive effects on the service sector and negative effects on agriculture and industry. In summary, the paper concludes that increasing the temperature by 1.0 °C, leads to a loss in GDP by 2.5%. The paper recommends including climate change in Uganda's modelling frameworks. This paper focuses on the temperature and rainfall and does not look at the effects of adverse weather effects and/or sectoral effects. In addition, it recognizes the gap of having climate change incorporated in the climate change modelling frameworks. We envisage addressing this research gap by using Uganda's CGE model to assess climate change adaptation and mitigation fiscal options.

Tumwine *et al.* (2019) applied the Ricardian Panel Tobit technique on the Ugandan economy to assess the effects of climate change on agricultural crop returns in Uganda. The paper found out that 67% of agricultural risks are climate related. Regarding the use of irrigation as a mitigation measure in Uganda, the paper found that less than 2% of the farming households practice irrigation, although farmers practicing irrigation earn more compared to their counterparts. This reveals the extent of Uganda's vulnerability to climate change.

The paper found differentiated effects of climate change on different sectors in Uganda. For instance, an increase in temperature by 1% decreases returns of farms dealing in maize, banana, cassava, and beans; while a 1% increase in rainfall would lower returns for banana, beans, cassava, and maize but increase returns for ground nuts. The paper recommends Uganda embraces a multi-pronged policy package of extensive irrigation, agricultural insurance, and food cribs during a bumper harvest and agricultural diversification. *Ibid* calls for adaptation measures which we envisage to assess in this paper.

Blending mitigation and adaptation has widely been captured in literature. For instance, Barrage (2015) used a CGE model to study the fiscal perspective of climate change adaptation and mitigation. The paper explores the implications of distortionary taxes for the trade-off between adaptation and mitigation measures. That is, mitigation measures like carbon taxes would raise revenue with welfare costs on other taxes. The findings of the paper show that government investment in adaptive capacity reduces utility losses and infrastructure damages. The carbon tax is implemented like any tax on commodities. The paper concludes that the welfare costs of limiting climate policies (like a carbon tax) are likely to be twice as high as the distortionary costs of adaptive expenditures. In addition, Washida and Sakaue (2014), used an environmental damage and adaptation (EMEDA) model to simulate the economic impacts of tropical cyclones. The paper identifies the increasing usage of CGE models for simulating global warming and assessing the economic damages caused by climate change. However, the paper mentions a research gap in modelling climate change economic effects on sectors of the economy and at a global level. Zeshan and Shakeel (2023) used a CGE model focused on water and energy to study the adaptation and mitigation policies for climate change. The paper brings in a unique facet of the cross effects of mitigation and adaptation policies.

CGE models have also increasingly been used in literature to study the existence of spill-over effects of developed countries' climate policies on developing economies. Boccanfuso et al. (2013) used a macro-micro CGE model to assess the distributional impact of developed countries' climate policies on Senegal. The study found strong cushioning benefits of transitioning to clean electricity, which would protect poor households against the increased world price of fossil fuels and loss in agricultural productivity due to climate change events. The paper found that adaptation policy measures like irrigation have the potential to reduce output losses caused by mitigation policies in South Asia. Thus, the literature shows a versatile use of CGE models in climate policy analysis.

The above review of the literature shows a gap in the economy-wide modelling of climate change adaptation and mitigation in Uganda. Scholars like Sebukeera *et al.* (2023) call for the incorporation of climate change in Uganda's macroeconomic modelling frameworks. It is against this background that we envisage addressing this research gap by using the CGE model to assess climate change adaptation and mitigation in Uganda. In addition, we also focus on fiscal policy response options to climate change; an area that is not captured in the literature. In summary, this paper provides fiscal policy guidance based on practical economy-wide fiscal policy analysis in relation to climate change options of adaptation and mitigation. In addition, the paper approaches climate change differently by focusing on carbon tax and extreme weather conditions like floods, other than the long-term effects of changes in temperature and precipitation in literature.

3. Theoretical transmissions of climate change on output, productivity, and infrastructure

The theory that relates climate change to the economy has widely been based on the extensions of the Solow growth model, and the Ramsey-Cass-Koopmans growth model. The former provides the transmissions mechanism through which climate change affects economic growth, via its effects on labour productivity. The latter extends this notion by including the damages of climate change on capital stock.

3.1 Climate-Solow model

The Climate-Solow growth model[1] provides the economic theory that relates climate change to economic output, growth, savings, population and technological progress.

The Climate-Solow model assumes constant returns to scale in the output generation process using capital stock, labour force and technology advancement. Romer (2006) uses Solow's growth model to describe the theory *growth miracles'* and '*growth disasters'* The former is when the growth of a country is persistently above the global average, and the latter is when it is persistently below the global average. The Solow model focuses on output $(Y(t))$, capital $(K(t))$, labour $(L(t))$ and knowledge or effectiveness of labour $(A(t))$ as demonstrated below.

[1] This is an extension of the Solow Growth Model to incorporate climate change analysis.

$$Y(t) = F[K(t), A(t)L(t)]$$

Output would only change if inputs change, depicting either '*growth miracles*' or '*growth disasters*' or a mixture of both. Casey *et al.* (2023) extended the Solow growth model to incorporate climate change as part of the '*growth disasters*'. The inclusion of the climate change damages is done by modifying the *Cobb-Douglas* production function. This splits Total Factor Productivity (TFP) into the *growth effect* of climate change and the *level effect* of climate change. This capitalises on the ability of the Solow model to distinguish between transition (temporary) and the steady state (permanent):

$$Y(t) = TFP(t)K(t)^{\alpha}L(t)^{(1-\alpha)}$$

$$K(t+1) = I(t) + (1-\delta)K(t)$$

Where $I(t)$ is investment and $K(t)$ is capital stock in period(t). Casey *et al.* (2023) propose the modification of TFP with D_g to capture the *growth-effect damage function* of the relationship between the TFP growth rate and the damage, and D_l to capture the *level effect damage function* or the relationship between climate and the level of TFP. We use $Temp(t)$ to describe the average temperature of the year (t); a variable that represents climate change and link it to the damages by parameters D_l and D_g.

$$TFP(t) = D_l(Temp(t))\widetilde{TFP(t)}$$

$$TF\widetilde{P(t+}1) = \left[1 + g + D_g(Temp(t+1))\right]\widetilde{TFP(t)}$$

Casey *et al.* (2023) outline the model in the form of two scenarios; the growth effects are simulated while having $D_l = 0$ whereas the level effects function of climate change is activated while keeping $D_g = 0$.

3.2 Ramsey-Cass-Koopmans growth model of climate change

The Ramsey-Cass-Koopmans growth model of climate change complements the Climate-Solow model in providing the theoretical transmission channels of climate change to the economy. In addition to the labour productivity impact channel, the Ramsey-Cass-Koopmans growth model also demonstrates the effects of climate damages on capital stock. This is captured through an accelerated depreciation rate.

This theory of climate and growth is increasingly dominating the literature. Some scholars like Akram (2012) and Fankhauser and Tol (2005) have used the Ramsey-Cass-Koopmans growth model of climate change to explain the effects of climate change on the economy. This model postulates a planner whose objective is to maximise the utility (u) of identical consumers subject to the intertemporal labour earnings and capital accumulation equation as specified below.

$$max \int_0^{\infty} u(c, Temp)e^{(n-\rho)t}dt$$

Subject to:

$$\dot{K} = F(K, L, Temp) - cL - \delta(T)K$$

$\dot{L} = n(Temp)L$ and $n = p + ltfp$

Where, $Temp$ is the climate change variable (temperature), c is per capita consumption, $F(K, L, Temp)$ is output, δ is depreciation, ρ is the discount factor, L is labour supply, and K is capital stock. The model assumes labour supply starts at the normalised level of 1, and grows by the rate n, – p $ltfp$ $ltfp$ is set to be endogenous. In the setup of Ramsey-Cass-Koopmans growth model $Temp$; whose size dictates the impact of climate change on the economy. That is, the larger the $Temp$, the more impactful climate change will be on the economy.

Fankhauser and Tol (2005) hypothesise that climate change has negative effects on household utility $\left(\frac{\partial u}{\partial Temp} < 0\right)$, output $\left(\frac{\partial F}{\partial Temp} < 0\right)$, health and mortality $\left(\frac{\partial n}{\partial Temp} = n_{Temp} < 0\right)$ and deteriorates capital stock or reduces the durability of capital.

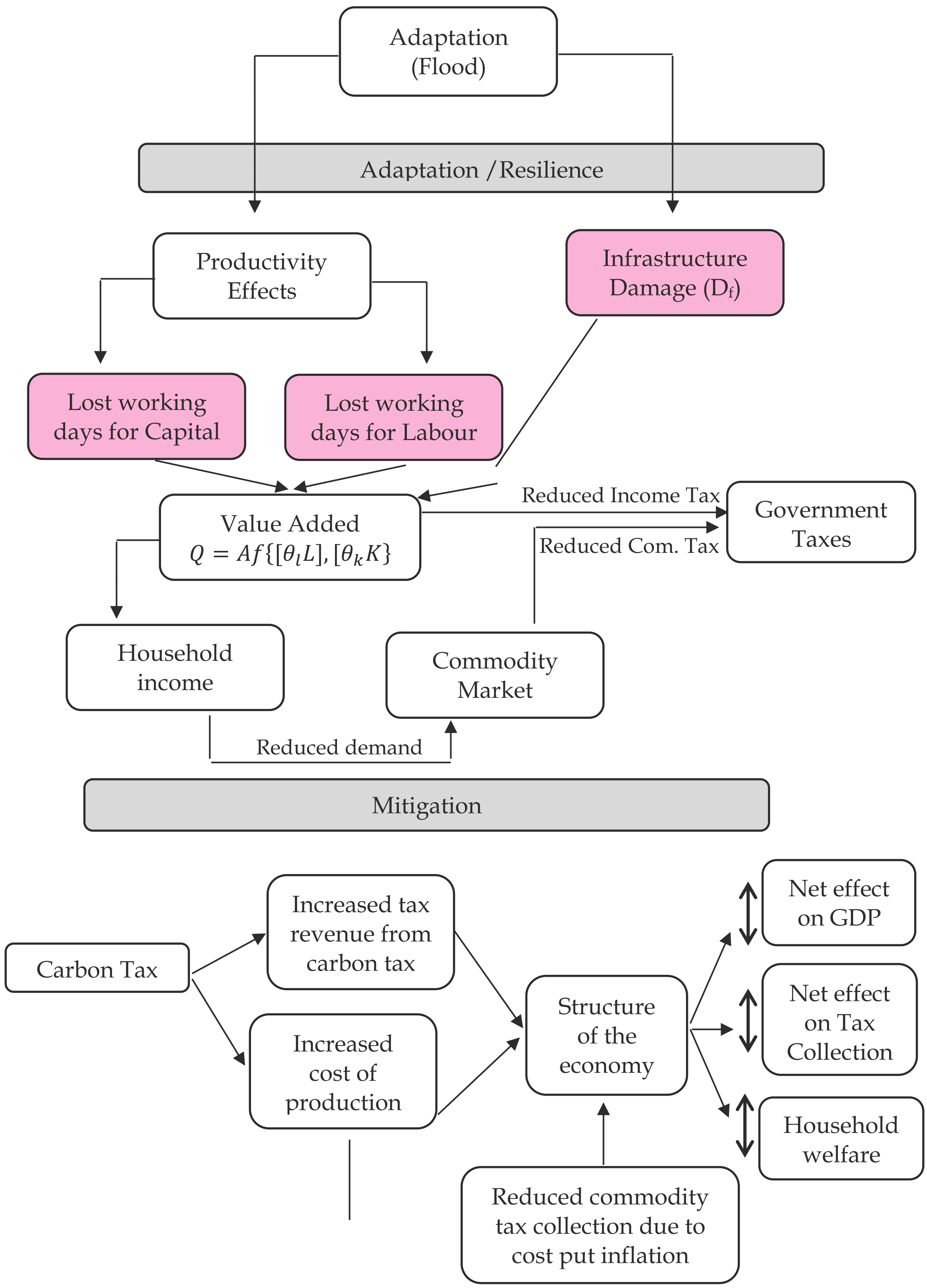
Akram (2012) shows that both the Solow's model and the Ramsey-Cass-Koopmans growth model of climate change postulate that; climate change deteriorates economic output which reduces investment. So, in the long run, capital stock and consumption per capita declines, which reduces economic growth. They also assert that the slow accumulation of capital stock can have serial improvements in labour productivity, which deepens the total long-term impact on economic growth. The models discussed in this theoretical framework have been applied using both economy-wide Computable General Equilibrium (CGE) models, and time-series models.

3.3 Conceptual framework of adaptation and mitigation to climate change

Based on the above theoretical background, we can derive the conceptual framework for adaptation and mitigation. We can conceptualise adaptation to reduce the effects of adverse weather events on the economy, and we can hypothesize two transmission channels of climate change hazards. The first is through infrastructure damage and productivity slowdown. Damages to the infrastructure reduce productive capital stock, whereas lost working hours due to extreme weather reduces productivity for labour and capital. This leads to a contraction in value-added, household factor incomes, and demand. Consequently, tax collections are reduced. Figure 1 shows that adaptation to climate change effects should focus on shielding the loss in productivity of capital and labour, as well as damages on capital stock.

To comply with the target of the Nationally Determined Contributions (NDCs), we introduced mitigation measures. Here, we introduce a carbon tax which increases production costs and generates some additional tax revenue. The cushioning effects of mitigation on the economy (tax, growth, and welfare) depend on the structure of the economy as shown in Figure 1. In the subsequent sections, we empirically use a Computable General Equilibrium (CGE) model to assess the economic implications of mitigation.

Figure 1: Conceptualisation of Adaptation and Mitigation



4. Methodology

4.1 CGE model customisation to climate change

We propose to use an economy-wide model to assess the impact channels of climate change-related hazards like floods and droughts. In this class of models, the Computable General Equilibrium (CGE) model will be used. The blocks of this model will be developed following Sadoulet and de Janvry (1995). The nesting is shown in Appendix 1. The modification to the CGE model to capture climate change adaptation and mitigation options are discussed below.

4.1.1 Production function

The production follows a Constant Elasticity of Substitution (CES) function to combine factors in the production process. To demonstrate this, let q be a production function, a the scale parameter, α a share parameter, and θ_0, θ_k, θ_l efficiency parameters (neutral, capital saving and labour-saving technologies); and ρ transformation of elasticity of substitution between capital and labour. The CES is demonstrated below.

$$q = a\theta_0[\alpha(\theta_k k)^{-\rho} + (1-\alpha)(\theta_l l)^{-\rho}]^{-1/\rho} \tag{1}$$

$\rho = \frac{1-\sigma}{\sigma}$ and $\sigma = \frac{1}{\rho+1}$; thus, $-1 < \rho < 0$ for $\sigma > 1$ and $0 < \rho$ for $\sigma < 1$ and $a>0$

4.1.2 Consumption demand function

Consumer behaviour in the form of indifference between consumption of domestic and imported commodities would be captured using an Armington function (Constant Elasticity of Substitution – CES). Let's denote *m* for imports, *pm* for the price of imports, *d* for domestic commodities, and *pd* for the price of domestic commodities. Following the optimisation problem and the respective Lagrangian function, we derive the following equilibrium solutions which define consumer decisions:

$$\frac{m}{d} = \left(\frac{pd}{pm}\frac{\delta}{(1-\delta)}\right)^{1/(1+\rho)} = \left(\frac{pd}{pm}\frac{\delta}{(1-\delta)}\right)^{\sigma} \tag{2}$$

The individual consumption functions would follow the Linear Expenditure System (LES) derived from the Stone-Geary utility function, which is pointwise separable. For demonstration, c_i is the minimum subsistence consumption that cannot fall, and b_i is the marginal budget shares. The utility function is shown in Eq (3) and the Linear Expenditure System (LES) in Eq (4).

$$u = \prod_{i=1}^{n}(q_i - c_i)^{b_i} \quad or \quad u = \sum_{i=1}^{n} b_i \ln(q_i - c_i) \quad with \begin{cases} 0 < b_i < 1 \\ \sum_i b_i = 1 \\ q_i - c_i > 0 \end{cases} \tag{3}$$

$$p_i q_i = p_i c_i + b_i\left(y - \sum_j p_j c_j\right), \quad i = 1, \dots, n. \tag{4}$$

4.1.3 Incorporating energy inputs in the CGE model

We propose to use a nested CES function (q (5), to aggregate biomass ($BIOM$) and non-biomass energy inputs ($NONBIOM$) into total energy inputs. Then, Eq (7), would form a CES function for aggregating non-biomass energy input including electricity ($ELEC$) and fossil fuel energy ($FOSSIL$),like petrol, diesel, and kerosene. At the lower nest, biomass, electricity, and fossil fuel energy sources are also governed by a CES. Then, XST_j total aggregate outputENG_j aggregate energy intermediate consumption by industry j, and$ioegy_j$ is the energy intermediate Leontief coefficients.

$$ENG_j = ioegy_j XST_j \tag{5}$$

$$ENG_j = B_{INT(j)}\left[\beta_{INT(j)}\ BIOM_j{}^{-\rho_j} + (1-\beta_{INT(j)})\ \ NONBIOM_j{}^{-\rho_j}\right]^{-\frac{1}{\rho_j}} \quad (6)$$

$$NONBIOM_j = B_{ELCFS(j)}\left[\beta_{ELCFS(j)}\ \ ELEC_j{}^{-\rho_j} + (1-\beta_{ELCFS(j)})\ \ FOSSIL_j{}^{-\rho_j}\right]^{-\frac{1}{\rho_j}} \quad (7)$$

4.1.4 Incorporating carbon emissions in the CGE Model

We propose to customise the standard CGE model to incorporate Greenhouse Gas Emissions (carbon dioxide equivalent) from the intermediate use of energy goods. We demonstrate this in Eq (8); where $ICO2O$ is total carbon dioxide emissions from the intermediate consumption of energy commodityIP; which is computed as the carbon dioxide emissions coefficient of commodity $emcco2(ip)$; and intermediate consumption of that particular energy good ip in sector $DIO(ip, jap)$; divided by the base year conversions coefficient, $\frac{1}{convcoff(ip)}$.

$$ICO2O(IP) = \left[\sum_{jap=1}^{n} emcco2(ip) * \frac{1}{convcoff(ip)} * DIO(ip, jap)\right] \quad (8)$$

4.1.5 Adaptation: Damage function customisation in the CGE model

Adaptation to climate-related natural disasters like floods, landslides, and droughts would require adjusting the CGE production function to capture the (a) loss of output, destruction of public and private infrastructure and household units, and (b) upgraded to design adaptive scenarios that would support the construction of climate resilient infrastructure, irrigation, use of clean energy to replace biomass energy, investments in productivity enhancement especially agriculture (crop yield) and labour productivity.

Damages by climate change hazards call for replacement costs that crowd out priority expenditures and disrupt prudent investment patterns. Equation (9) is the modified production function with productivity parameters for capital (θ_k) and labour (θ_l), that capture the lost hours of work due to climate change. The respective resilience parameters for capital and labour are captured by ϕ_k and ϕ_l respectively. Equation (10) is the capital commutation with δ signifying depreciation rate, D_t is the damage to capital stock described by Burns *et al.* (2021); I_t^R is the investment allocated to repair capital and $\phi_{\mho,t}$ is the adaptation or resilience parameter. Parameter A is Total Factor Productivity.

$$f(L, K) = A\left[\alpha(\theta_k \phi_k K)^{-\rho} + (1-\alpha)(\theta_l \phi_l L)^{-\rho}\right]^{-1/\rho} = q \quad (9)$$

$$K_t = (1 - \mho_t)K_{t-1} + I_t \quad (10)$$

$$\mho_t = \delta + \phi_{\mho,t}(D_t - I_t^R) \quad (11)$$

4.1.6 Mitigation: Modelling carbon tax in the CGE

Carbon taxation demonstrates the options of possibilities to align decisions of economic actors to climate change mitigations. For example, reducing greenhouse gas (GHG) emissions, and restoring the quality of natural resources like water and aquaculture harvests. We propose to model carbon price as an explicit price of GHG emissions per tonne of carbon dioxide equivalent (tCo2e) from a given energy source. The range of carbon prices across the existing initiatives are broad, ranging from less than US$1/tCO2e to US$131/tCO2e (World Bank, 2016). Carbon pricing is still an evolving process and continually expanded to cover a wider range of GHG emissions sources. Our baseline carbon price[2] covers energy sources including firewood, charcoal, petrol, diesel, and kerosene. To capture this, we use variable CARB (ip) in Eq (12) as the baseline carbon tax revenues from the energy good ip. All

[2] In the model baseline, we set the price of a tonne of carbon dioxide at 3 dollars, and this translates to UGX 10,500/tCO2e.

energy goods are consumed as intermediate inputs in the different activities and as final goods by households; and none will be exported. Therefore, total carbon tax revenues are determined by multiplying the carbon price $co2pxo$ by the emissions from intermediate use $\sum_{jap=1}^{n} DIO(ip, jap)$ and household final consumption $\sum_{jag=1}^{n} CO(ip, jag)$, minus any associated with exports. Thus, variables; $emcco2(ip), emcch4(ip), and\ emcn2o(ip)$ relate to carbon dioxide, methane, and nitrous oxide emissions coefficients expressed in carbon dioxide equivalent. The coefficient $convcoff(ip)$ represents the conversion factor of the quantity of commodities to volumes.

$$CARB(ip) \quad = \{co2pxo * [emcco2(ip) + emcch4(ip) + emcn2o(ip)] * [\sum_{jap=1}^{n} DIO(ip, jap) + \sum_{jag=1}^{n} CO(ip, jag) - EXDO(ip)] * 1/convcoff(ip)\} \quad (12)$$

The carbon tax revenue is then used to calculate the tax rate per unit of energy consumed. This is specified as shown in Eq (13).

$$cbtaxo(i) \quad = \quad CARB(ip)/\{(PLO(i) + \sum_{ij=1}^{n} PCO(ij) * tmrg(ij, i) * DDO(i) + (eO * PWMO(i) + \sum_{ij=1}^{n} PCO(ij) * tmrg(ij, i)) * IMO(i) + \ TIMO(i)\} \quad (13)$$

Where $PLO(i)$ is the price of local product i (excluding all taxes on products), $PCO(i)$ the purchaser price of composite commodity i (including all taxes and margins), $tmrg(ij, i)$ the rate of margin ij applied to commodity i, $DDO(i)$ the domestic demand of local production of commodity i from industry j, eO the exchange rate, $PWMO(i)$ world price of imported product i expressed in foreign currency, $IMO(i)$ the quantity of product i imported, and $TIMO(i)$ the import duties on imported commodity i, which includes all commodities. Note that set ip is only a subset of set i of all the commodities; hence, the above equation relates to commodities in set ip, which is comprised of energy carriers like firewood, charcoal, petrol, diesel and kerosene.

4.1.7 Dynamic equations

Inclusion of dynamic equations transits the static CGE mode to a recursive dynamic CGE model. The dynamic equations include accumulation of capital stock (KD), as shown in Eq (14). The investment function borrows from the approach proposed by Bourguignon et al. (1989) and Jung and Thorbecke (2003). The capital accumulation rate follows the ratio of the rate of return to capital to its respective user cost of capital. The user cost of capital ($U_{i,t}$) is approximated as the dual price of investment ($Pinv_t$) multiplied by the sum of depreciation (δ_i) and the real interest rate (ir) as shown in Eq (15). This is used to make decisions on how we allocate the new capital to capital categories and sectors. We the investment demand specification proposed by Jung and Thorbecke (2001); that new capital should be allocated to enterprises or firms proportional to the existing capital stock. This proportionality varies following the $Tobin's\ q$ which is the ratio of rental rate of capital and the user cost of capital as shown below.

$$KD_{i,t+1} = (1 - \delta)KD_{i,t} + Ind_{i,t} \quad (14)$$

$$U_{i,t} = Pinv_t(ir + \delta_i) \quad (15)$$

$$Invk_{i,priv,t} = \phi_{i,priv} \left[\frac{R_{i,priv,t}}{U_{i,priv,t}}\right]^{\sigma_{i,priv}^{INV}} KD_{i,priv,t} \quad (16)$$

Where $\phi_{i,priv}$ is the scale parameter, $R_{i,priv,t}$ is the rental rate for capital, $U_{i,priv,t}$ is the user cost of capital, ir_t is the interest rate and $\sigma_{i,priv}^{INV}$ is the elasticity of private investment demand relative to $Tobin's\ q$. We follow the balanced growth path where exogenous variables like labor supply grow at the same constant rate of population growth rate. $Popn_t = Popn_{t-1}[1 + \eta_{t-1}]$; where η_{t-1} is the population growth rate.

4.2 Data for the model

The main data source for this project is the 2016/17 Social Accounting Matrix (SAM) for Uganda. This is complemented by emissions data (of 2017) from the national emission inventory housed in the Ministry of Water and Environment. Data on volumes of biomass and non-biomass energy goods was sourced from the Ministry of Energy and Mineral Development for the year 2017.

4.3 Scenario design

The paper is based on the assessment of the cushioning effects of adaptation and mitigation measures, on the effects of climate change on the economy. First, for the adaptation scenario, we simulate a flood that halts the employment of capital and labour for four weeks in the agricultural sector and washes away 0.5% of the infrastructure. We compare the results with an additional shock of increasing resilience of infrastructure by 20%. This shields the economy through reducing the potential damage of adverse climate change events. The second scenario assesses the use of carbon tax as a mitigation of carbon emissions; by increasing carbon tax rate by half. Increasing the tax is used as a mitigation tool to curb emissions. The scenarios are summarised in Table 1.

Table 1: Scenario design

	Climate change hazard and government response	**Scenario description**
		Adaptation scenario
No.1	Flood	Four weeks of lost time for labour and capital in the agriculture sector 0.5% damage to the infrastructure for all sectors of the economy
No. 2	Adaptation measure	Increase the economy's resilience to climate change effects by 20%
		Mitigation scenario
No. 3	Mitigation measure	Increase the carbon tax by a half-fold and observe the effect on the carbon emissions and costs to the economy

5. Results

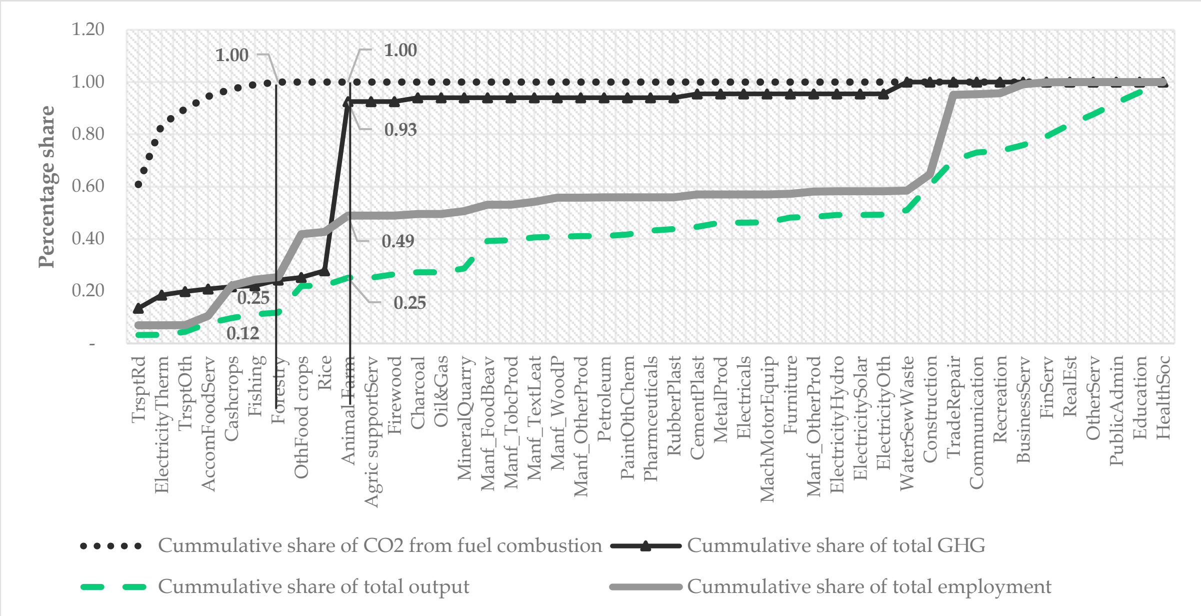
The results discussed below assess two scenarios on adaptation and mitigation measures for climate change effects. Prior to the discussion of the model results, we first assess the structural relationship between emissions, economic output and employment. This assessment is key to identifying sectors driving GHG emissions compared to their contribution to economic activity and employment. In the next sub-section, we discuss the model results of climate change adaptation and mitigation measures. This covers two scenarios; first, we assess the cushioning effects of mitigation measures on climate change effects. Secondly, the use of carbon tax as a mitigation measure for carbon emissions as a drive to attain the Nationally Determined Contribution (NDC). The following sub-sections begin with the discussion on the economic impact of floods in Uganda Section 4.1. This is followed by the discussion of the climate change adaptation (in section 4.2) and then section 4.3 which discusses the mitigation options.

5.1 GHG Emissions structure relative to economic activities

In this section, we assess the relationship between emissions of GHG, economic output and employment. The cumulative relationship is depicted in Figure 1, which shows that emissions in Uganda are largely derived from activities that contribute a quarter of the national output. These include transport, thermal electricity, hotel and accommodation, cash crops, fishing and forestry.

These account for 93% of greenhouse gases (GHG) and account for 25% of economic output and employ about half of the population as shown in Figure 1. In addition, sectors engaged in the combustion of fossil fuel as a source of energy account for only 12% of economic output and a quarter (25%) of total greenhouse gases (GHG). Thus, these results imply that at the national level, sectors responsible for three-quarters of economic output do not have a significant contribution to the accumulation of emissions in Uganda. This provides guidance regarding policy targeting in the areas of climate change mitigation measures. The results are shown in Figure 2.

Figure 2: Structure of emissions, output and employment in Uganda



Source: Own calculations using data from Uganda Bureau of Statistics (UBOS).

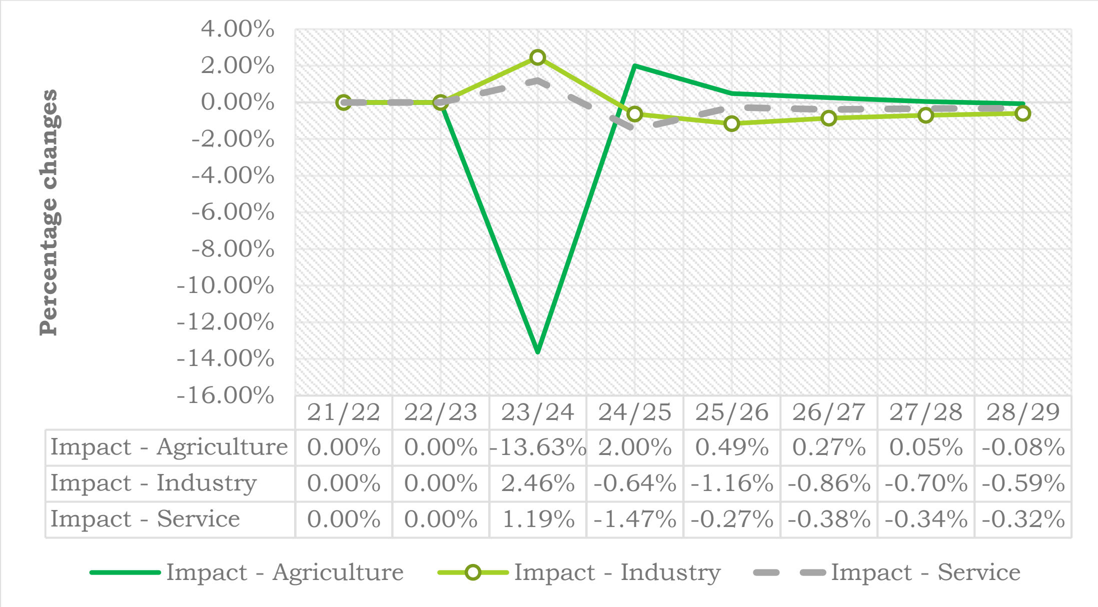
5.2 Economy-wide impacts of climate change hazards - floods

In this section we provide an assessment of the impact of climate change hazards, specifically floods, on the economy. We simulate a four-week halt of agricultural work due to floods which also wash away 0.5% of the infrastructural capital stock. We simulate only the damage of floods on capital stock and operational time for labour and capital (productivity). In this section we cover the impact of floods on productivity (section 4.1.1), economic growth (section 4.1.2), tax collections (section 4.1.3), and savings for enterprises and households (section 4.1.4).

5.2.1 Impact on labour productivity

Floods affect economic sectors by destroying infrastructure and creating redundancy of factors of production. These effects deteriorate labour productivity across all sectors. The results in Figure 3 show that agricultural productivity is the most affected, compared to industry and service sectors. In the year of the floods, productivity of agriculture deteriorates to a tune of 13.6%, however productivity for industry and service improve due to reduced factor prices and thereafter deteriorates in the medium term as agriculture recovers back to the steady state. Although productivity recovers in the medium term, it should be noted that the policy scenario remains below the baseline in the medium term. This emphasises the need for government intervention to safeguard productive sectors against extreme climate change events like floods. Such intervention would focus on strengthening adaptation measures that increase resilience of the productive sectors.

Figure 3: Impact of floods on productivity



	21/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29
Impact - Agriculture	0.00%	0.00%	-13.63%	2.00%	0.49%	0.27%	0.05%	-0.08%
Impact - Industry	0.00%	0.00%	2.46%	-0.64%	-1.16%	-0.86%	-0.70%	-0.59%
Impact - Service	0.00%	0.00%	1.19%	-1.47%	-0.27%	-0.38%	-0.34%	-0.32%

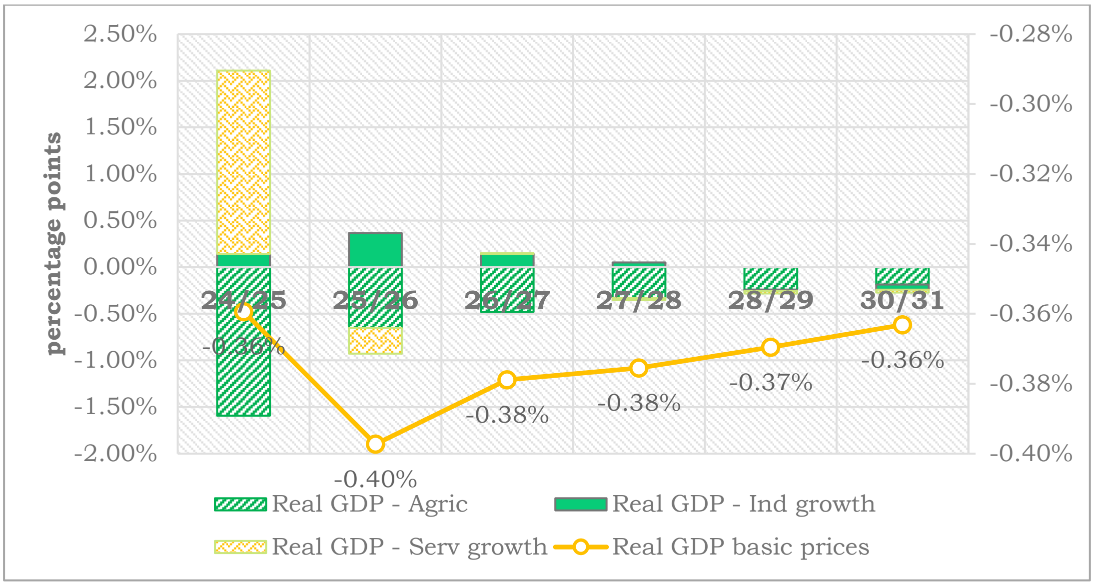
5.2.2 Impact on Economic Growth

Extreme climate change events like floods halt sectoral output and derail transactions; thus, affecting economic growth. The effect on economic growth is mainly through the impact on agricultural labour and capital productivity as well as the damages made to productive infrastructure. The results in Figure 4 show that when labour and capital lose four weeks of productive time due to floods and 0.5% of infrastructure capital is washed away; economic growth dampens by about 0.4 percentage points annually. However, the impact of floods is differentiated by economic sector.

The flood shock reduces activity and growth in the agricultural sector, forcing factors of production to move to the service and industry sector thus increasing their respective outputs in the initial year. Consequently, economic growth contracts in the first year (FY 2024/25) by 0.36 percentage points. The increase in the service sector output is short-lived as the sector faces a reduction in economic growth in the second period, by a further 0.4 percentage points in FY 2025/26. From here, the impact on service and industry subsides. Agriculture declines slowly in the medium term; thus, keeping economic growth below the baseline scenario as the economy recovers in the medium term. It should be noted that the effect on growth is persistent for some periods in the outlook mainly because the damage on infrastructure drags capital stock below the baseline for longer periods if rehabilitation of the lost capital is not implemented.

This shows that; floods affect all sectors in the economy negatively, however the effects on service and industry sectors are short-term whereas that on the agricultural sector is long-lasting; and this derails the recovery of economic growth. Based on these results, there is a need for the government to invest in adaptation measures that can shield agriculture production from extreme climate change events like floods. Adaptive measures could include adoption of high-land agricultural varieties, investment in water channels to minimise occurrence of floods and restoration of wetlands, as well as policies that reduce agricultural activities in floodplains.

Figure 4: Impact on economic growth and sectoral contributions



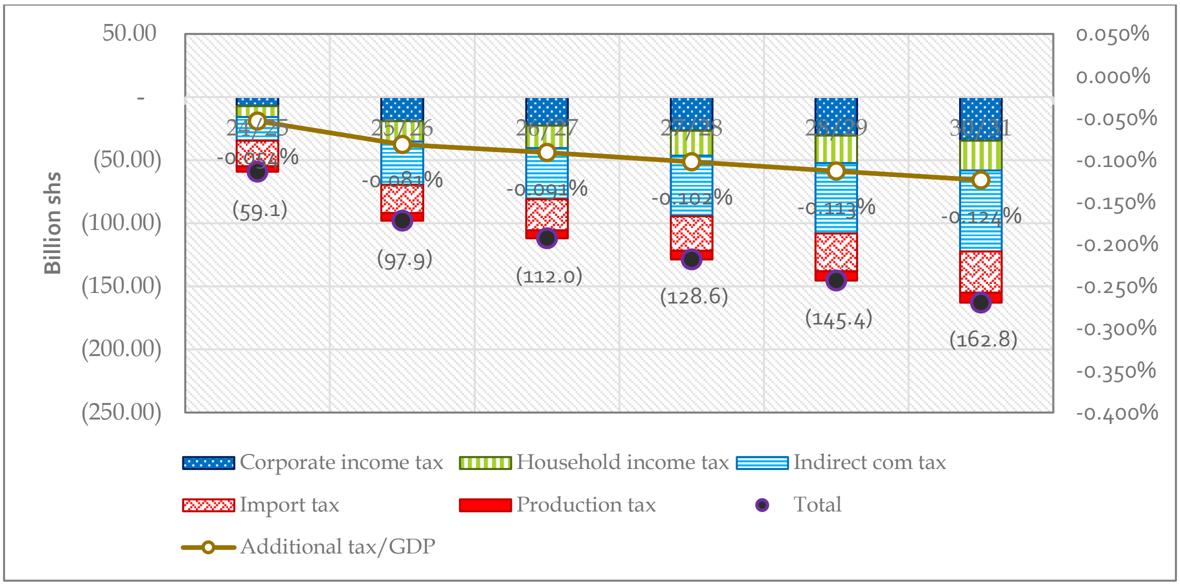
5.2.3 Impact of floods on tax collections

Floods have a reducing effect on economic growth which has retarding implication on incomes and expenditure patterns in the economy. The results in Figure 5 show that an annual average of four weeks of flood in Uganda would reduce tax collections by about UGX 59 billion in the first year (FY 2024/25) accumulating to UGX 161 billion by FY 2030/31. It should be noted that the first year of incidence has minimal effects on tax collections, mainly because the flood directly affects productivity in the agricultural sector (that hardly contributes to tax collections due to its informality)[3] and the affected factors of production transits to the service sector (taxable sector); thus, discounting the tax losses.

In the subsequent years, the output of the service sector contracts, increasing the tax-loss incidence across all sectors of the economy. The main affected tax heads are indirect commodity tax, income taxes, and import duties. The tax losses are mainly driven by the reduction in aggregate demand due to the flood shocks. Tax damaging effects of floods confirms the link between adverse climate change weather events and fiscal policy outcome. This affirms the need to invest in adaptations across the economy, especially in the agricultural sector.

[3] Agricultural sector is also largely tax exempt with major exemptions for tobacco and hides and skins.

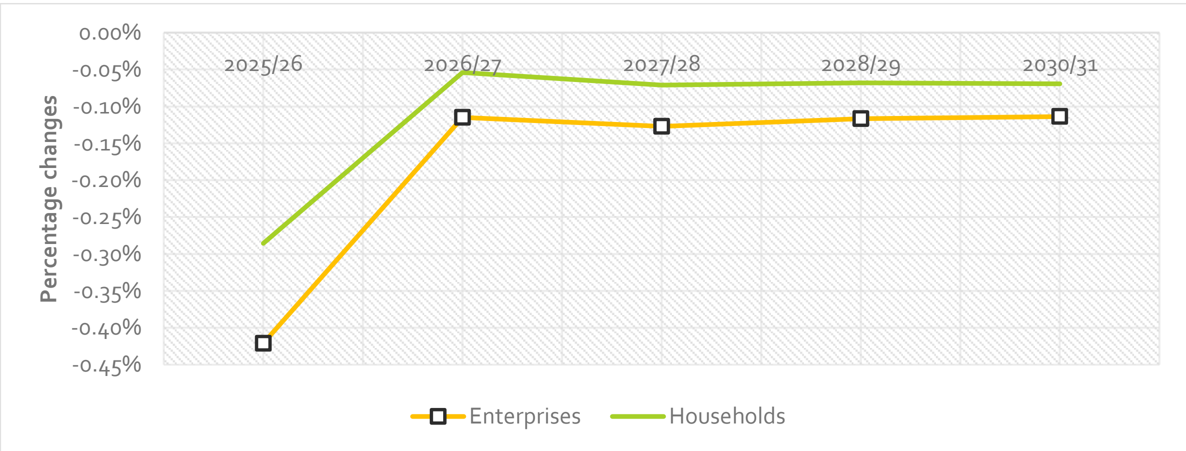
Figure 5: Impact in Tax Collection



5.2.4 Impact on enterprise and household savings

Floods disrupt economic production and reduce output. This deteriorates the incomes from sales, as well as increasing costs to the producing economic units which dampens factor incomes as well as firm and household savings. Figure 6 shows that, both firm and household savings decline; however, the impact on firm's savings is larger due to the flood effect on both income and production costs. In the medium term, the economy auto-corrects back towards the steady-state, although savings remain below the baseline as shown in Figure 6.

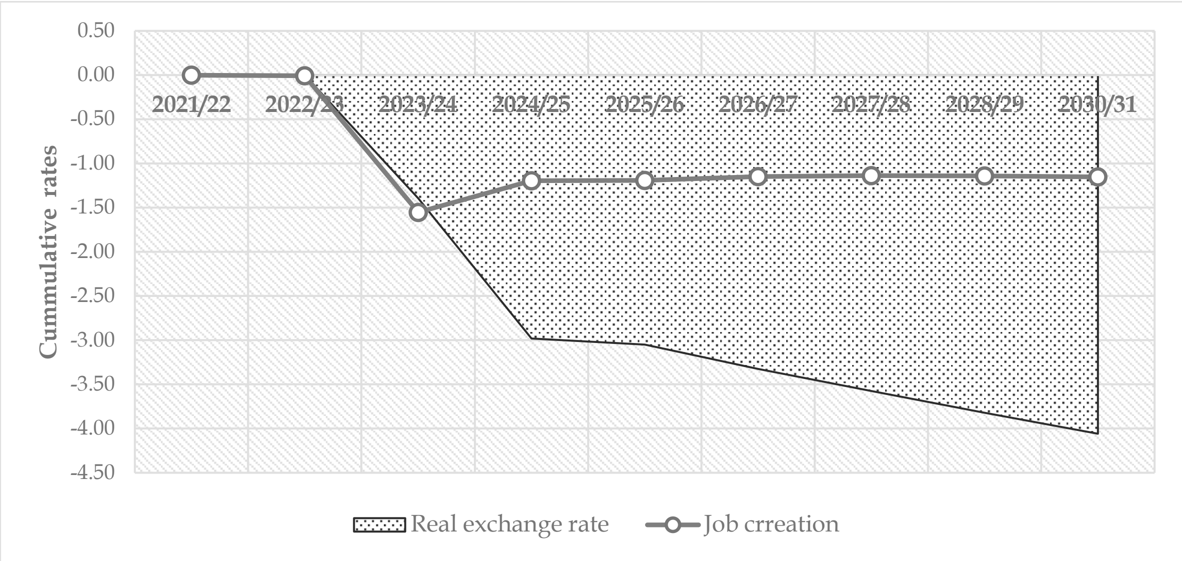
Figure 6: Changes in enterprise and household savings



5.2.5 Export competitiveness and job creation response to floods

We use the adjustments of the posterior real exchange rate (local currency per foreign currency) as a proxy for the competitiveness of Uganda's exports in the external markets. Real exchange rate appreciations driven by increases in domestic prices, would make Uganda's exports expensive whereas a depreciation would make them cheaper. Figure 7 shows that floods lead to real exchange rate appreciation as well as a decline in job creation. Cumulatively, the flood shock would appreciate the real exchange rate to a tune of 4.1 percentage points between FY 2024/25 and FY 2030/31. This has a reducing effect on Uganda's exports as they become more expensive to the international markets. In addition, the damages of floods on factor productivity and capital stock, dampens economic output as well as reducing real wages. This results into contraction of employment to a tune of 1.2 percentage points cumulatively by FY 2030/31. The results are show in Figure 7 below.

Figure 7: Cumulative impact on real exchange rate and employment



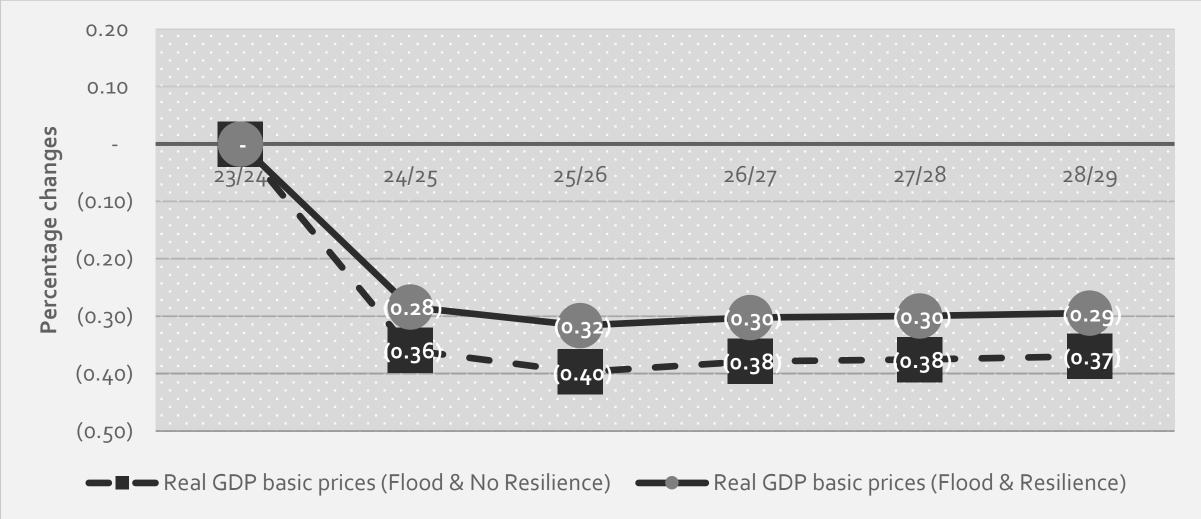
5.3 Simulating adaptation options to extreme weather events - floods

In this section, we discuss the quantified benefits of adaptation measures against climate change hazards like floods. We modify the flood scenario discussed in section 4.1 by including a 20% increase in the resilience of the economy to extreme climate hazards. We compare the flood impact results with a similar scenario where resilience to extreme climate hazards is improved. The results discussed in sections 4.2.1 – 4.2.4 show that adoption of policies that improve resilience to floods; reduce the damage to economic growth, tax collections, competitiveness and employment.

5.3.1 Economic growth response to floods and adaptation

The results show that adoption of policies that enhance resilience to adverse climate events; discounts the potential effects of such events like floods on the economy. Figure 8 shows that enhancement of climate resilience by 20% would reduce the losses in economic growth from an annual average of 0.4 percentage points, to about 0.3 percentage points annually. This shows that investing in climate change adaptation comes along with the benefits of cushioning Uganda’s economic growth against the damaging effects of climate change. The results are shown in Figure 8.

Figure 8: Adaptation and floods effects on economic growth

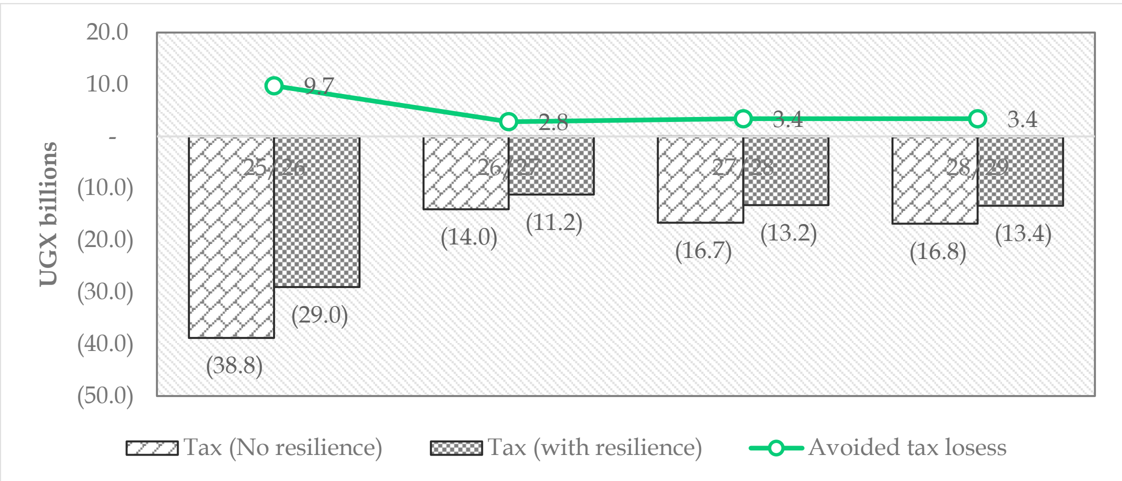


The above results also raise questions of the costs of investing in the economy's resilience to climate change. Studies like World Bank (2010) show that for a developing economy to have full resilience against climate change effects, it needs to invest about US$ 3 billion annually. Based on this estimation, to have the resilience of 20% used in this paper would require Uganda to annually invest US$ 600 million on expenditures related to improving economic resilience.

5.3.2 Adaptation and Tax Collections Response to Floods

The results in Figure 9 show that the adoption of climate change adaptation policies would increase the resilience of the economy to extreme weather events like floods. Improving resilience by 20% would reduce the damages of floods on tax collection from UGX 9.7 billion in the first period, and an average of UGX 3.2 billion for the rest of the periods in the medium term. In Uganda's policy arena, these results demonstrate the existence of the fiscal implicit benefits of investing in climate change adaptation. The results are shown in Figure 9.

Figure 9: Impact of climate change and adaptation measures on tax collections



5.3.3 Adaptation and Response of Export competitiveness and job creation to floods

In this section we discuss the results for the contribution of adaptation policies to the resilience of economies to extreme climate events like floods. The results show that, adoption of climate adaptive policies have the potential to reduce the vulnerability of economies to climate change related disasters. Figure 10 shows that a 20% improvement in economic resilience, would reduce the appreciation effect from an accumulation of 4.1% to 3.2% by FY 2030/31. This is largely due to the reduced effects of the floods on domestic prices, following improvements in resilience. Similarly, the number of jobs lost would reduce in the medium term as shown in Figure 11. It should be noted that by FY 2025/26, changes to employment return to the steady state.

Figure 10: Cumulative effects of floods and adaptation on the real exchange rate

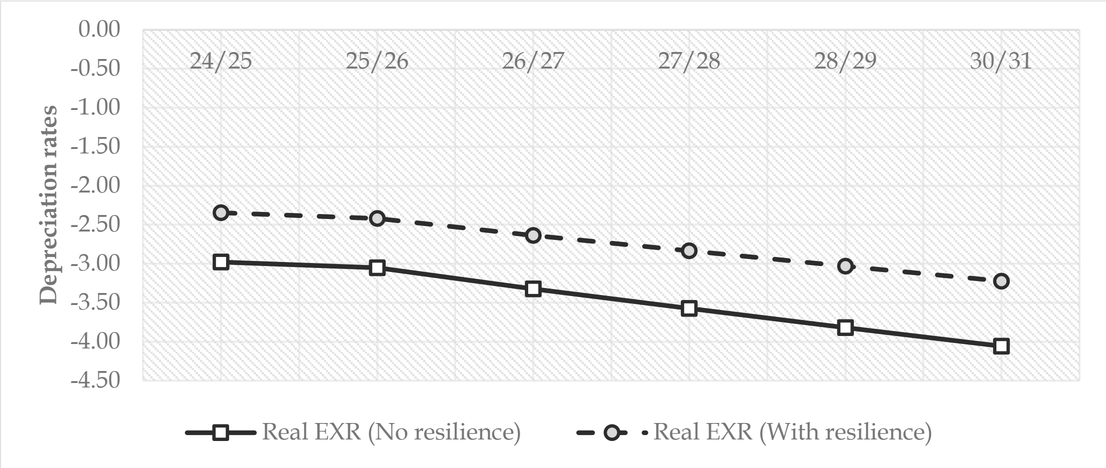


Figure 11: Impact of floods and adaptation on employment

5.4 Simulating mitigation measures to emissions – The carbon tax

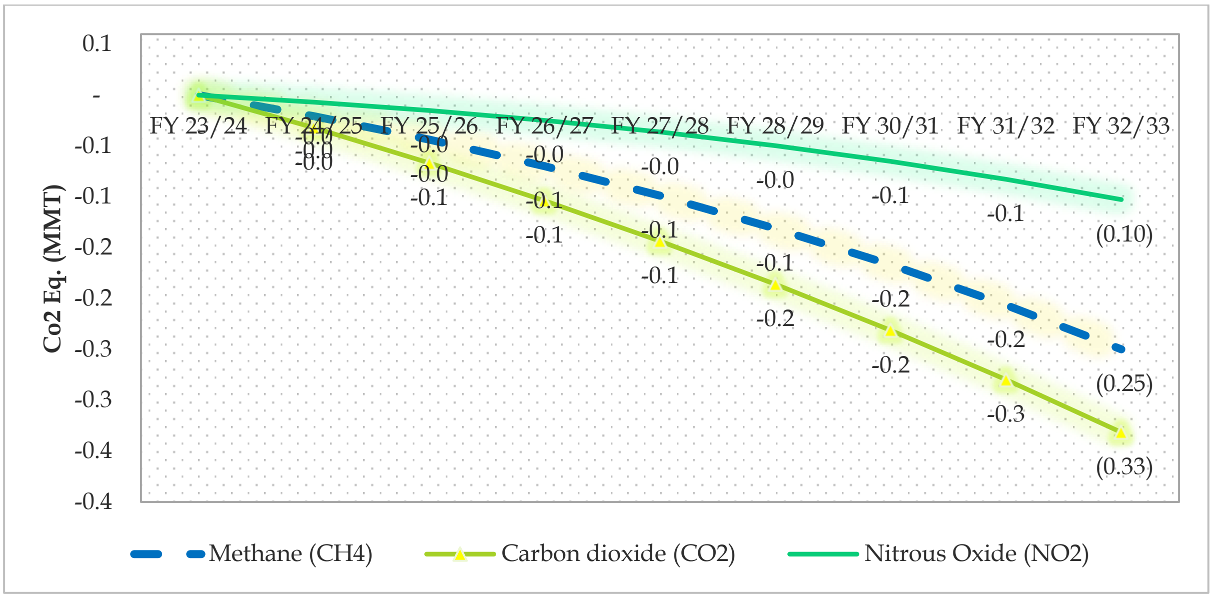
In this section, we assess the option of using carbon tax as a mitigation measure against climate change effects, through reducing the emission of greenhouse gases. This is inspired by the roadmap of the fulfillment of Uganda's commitments to the Nationally Determined Contributions (NDC). The updated national determined contribution (NDC) for Uganda (MoWE, 2022) requires that Uganda reduces emissions by 24.7% by 2030 as a mitigation contribution. The results presented below show that, the adoption of a carbon tax as a mitigation measure reduces emissions, thus contributing to the Nationally Determined Contribution (NDC). However, this comes at a cost of constraining economic growth and tax collections. Section 4.3.1 discusses the impact of carbon tax on emissions. This is followed by a discussion on the impact on economic growth and tax collections in sections 4.3.2 and 4.3.3.

5.4.1 Emissions (CO_2e) response to carbon tax as a mitigation measure

Economic activity requires complementary energy sources to produce output. This energy can be sourced from biomass and/or non-biomass sources like electricity and fossil fuels. Despite electricity being clean energy, fossil fuels are dirty energy due to their emissions during their energy conversion. In addition, this production process releases emissions, for example carbon dioxide (CO_2) in the production of clinker in the cement industry, nitrous oxide in the production of rice, and methane (CH4) from enteric fermentation among livestock. To ease aggregation, nitrous oxide and methane are converted into a carbon equivalent in metric tonnes (MtCO2e) using the Global Warming Potential (GWP)[4] conversion factors. The scenario assesses the effect of the carbon tax as a mitigation measure on emissions and the economy.

The results depicted in Figure 12 show that when the carbon tax rate is increased by half, the anthropogenic GHG emissions reduce by 0.68 MMT CO2e cumulatively by FY 2032/33, which amounts to an average of 0.086 MMT CO2e annual reduction in anthropogenic emissions as shown in Figure 12. This confirms that carbon tax would contribute to the reduction of emissions in Uganda, following the path set in the Nationally Determined Contributions (MoWE, 2022). Figure 12 shows that emission reduction is largely composed of Carbon dioxide (CO2) followed by Methane (CH_4) and Nitrous Oxide (N_2O).

Figure 12: Carbon tax as a mitigation measure for emission accumulation



5.4.2 Carbon tax effects on GDP and tax collections

The adoption of a carbon tax as a mitigation measure against emissions from productivity activities has shown to be effective in reducing these emissions. However, this comes at the cost of reducing the GDP returns despite the tax gains.

Figure 13 shows that carbon tax would discount the economic growth returns by an annual average of 0.04 percentage points, which accumulates to 0.3% of GDP lost by 2032/33. The reduction in growth is caused by a contraction in economic activity driven by higher costs of energy inputs among the productive sectors. This affects firm profits as well as reducing demand following the implicit cost-push inflation.

[4] The conversion factors for CO2e using the Global Warming Potential (100 years of time horizon) are: 1 for Carbon dioxide (CO_2), 25 for Methane (CH_4) and 298 for Nitrous Oxide (N_2O). These are based on the IPCC 4th Assessment Report (AR4).

Figure 13: Carbon tax effects on economic growth

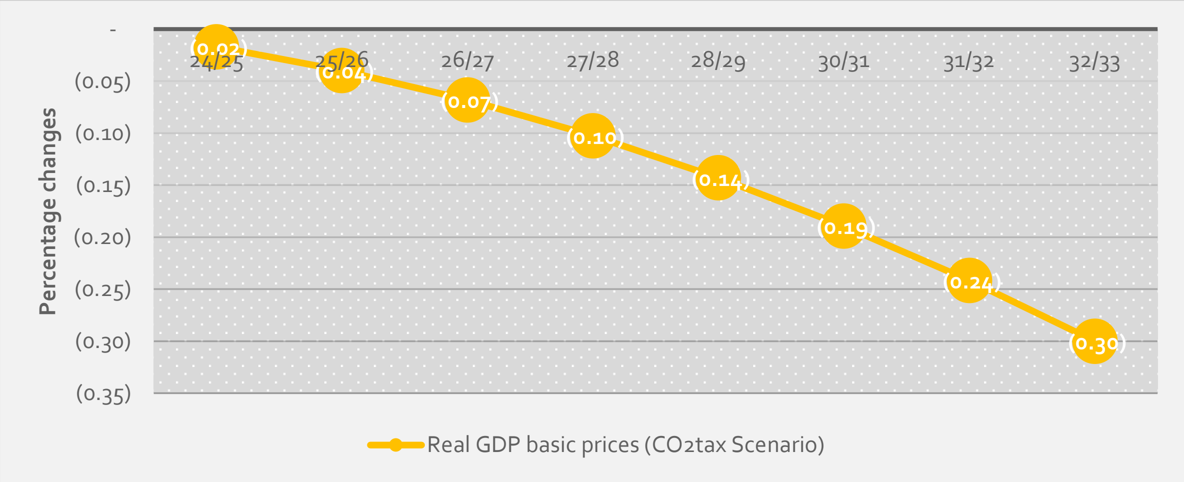
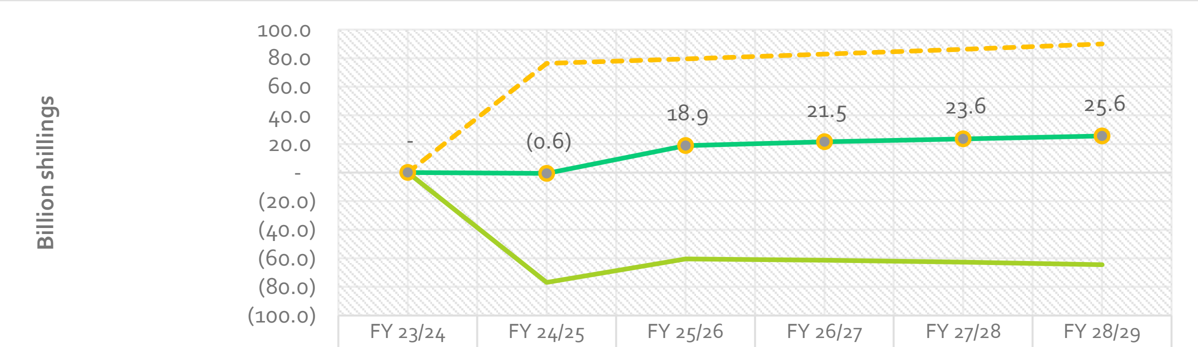


Figure 14 shows that the contraction in economic activity has a reducing effect on general tax collections, although it comes along with additional carbon tax gains. The effect on net tax is two-fold. First, the reduction in economic output reduces taxable commodities and profits leading to a decline in indirect and direct taxes. On the other hand, the increase in the carbon tax raises tax revenues to the government. Thus, the net of these tax-head flows dictates the net effect on tax collections.

Figure 9 shows that about UGX 76.8 billion is lost in tax because of a carbon tax on output in the first period. The carbon tax itself brings in UGX 76.3 billion, leading to a net tax loss of UGX 0.6 billion in the first period. In the rest of the period, carbon tax gains surpass the general tax losses leading to net tax gains of UGX 18.9 billion in FY 2025/26 and UGX 25.6 billion in FY 2028/29. The net tax losses steadily tail off as time evolves as shown in Figure 14.

Figure 14: Carbon tax effects on tax collection



	FY 23/24	FY 24/25	FY 25/26	FY 26/27	FY 27/28	FY 28/29
Additional tax from CO2 carriers	-	76.3	79.4	82.7	86.2	89.9
General Tax losses	-	(76.8)	(60.5)	(61.3)	(62.6)	(64.4)
Net additional tax	-	(0.6)	18.9	21.5	23.6	25.6

6. Conclusion and recommendations

Climate change and associated mitigation and adaptation measures hold a crucial position in policy discussions and require immediate and sustained attention from all sectors of society. The findings of this paper unveil the sources of GHG emissions and quantify the macroeconomic effects and their responses to policy mitigation and adaptation measures. The results show that greenhouse gas (GHG) emissions in Uganda are generated by sectors accounting for a quarter of economic output and employ about half of the working population. This is key for policy targeting, as adaptation and mitigation strategies should optimally address both the current impacts and future risks associated with a changing climate.

We found that building climate-resilient infrastructure capital reduces the effect of climate change hazards on macroeconomic outcomes like economic growth, tax collections, competitiveness and employment. We also found that the adoption of mitigation measures like carbon tax reduces GHG emissions from economic activities – although this comes at a cost of a minor reduction in economic growth which cumulatively can dampen growth in the long term. To cushion the effects of carbon tax measures on growth, the policy should be complemented using the proceeds to invest in climate-resilient infrastructure which would serve as a safety net for growth.

Based on the above results and conclusion, we propose the following continuum of recommendations. First, the need for the government to design enforceable national climate policies, like carbon pricing mechanisms and emissions reduction targets. This would require alignment of sectoral policies with climate goals, especially the key emitting sectors like energy, transport, and agriculture. This is contributory to the attainment of the National Determined Contributions (NDCs). Further studies could explore the option of combining carbon tax with transition to renewable energy sources such as solar, wind, and hydroelectric power. This would add extensive analysis geared to the attainment of the NDCs.

Since climate change adaptation is intertwined with economic growth, and the social welfare potential of the economy; there is a need for the government to increase investment in climate-resilient infrastructure. This policy measure would involve the development and maintenance of infrastructure that can withstand climate-related disasters such as floods, storms, and heatwaves and the adoption of nature-based solutions, such as wetland restoration for flood protection.

Finally, information asymmetry is a key driver of climate change; thus, there is a need for investment in research and development for new climate technologies and practices, including carbon capture and storage, and sustainable agriculture. This should be complemented by fostering collaboration between academic institutions, private sectors, and government agencies. To harness these recommended interventions, the government needs to also develop and implement comprehensive monitoring systems to track progress on climate goals and the effectiveness of adaptation measures.

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Appendix A

Nesting of climate variables in the production and supply functions of a CGE