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Clean energy transition and options for hedging fiscal policy against climate change damaging externalities

An Environmental DSGE model for Uganda

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Abstract

This paper employs an Environmental Dynamic Stochastic General Equilibrium (DSGE) model for Uganda to examine the macro-fiscal impacts of transitioning to clean energy in the face of climate change. The model incorporates climate damages, particularly on infrastructure, and assesses the effects of different emission tax revenue recycling options. Results indicate that the macroeconomic and fiscal consequences of clean energy policies crucially depend on how emission tax revenues are allocated. Subsidizing clean capital delivers the largest emissions reductions and accelerates the clean energy transition, making it the most effective strategy for achieving Uganda's Nationally Determined Contribution (NDC) target of a 24.7 percent emissions cut by 2030. However, this policy option imposes significant economic costs, including reduced output, consumption, employment, household welfare, and a deterioration of the fiscal position. Alternatively, using emission tax revenues to finance climate adaptation — aimed at shielding infrastructure and the broader economy from climate damages — generates better outcomes for economic growth, fiscal balance, tax revenues, debt accumulation, welfare, and real wages, though it is less aggressive in reducing emissions. This adaptation policy is also compared to other recycling options, such as lump-sum rebate transfers to households, which provide modest welfare gains but limited climate or fiscal benefits. The findings confirm a trade-off between macro-fiscal stability and clean energy transition objectives, emphasizing the need to integrate climate change policies into macro-fiscal frameworks. The paper contributes to the policy debate by quantifying the interactions between climate damages, adaptation investments, and clean energy transition policies, while recommending future research on emission tax policy implications for Uganda's emerging oil sector.

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1.0 INTRODUCTION

1.1 Background

The effects of climate change presents a significant challenge to the global economy and threatens the survival and descent livelihood of humanity. The increasing frequency of extreme weather events, rising temperatures, and changing rainfall patterns are negatively affecting economies of many countries especially those in Sub-Saharan Africa. According to the World Bank, response to extreme weather events like droughts and floods diverted up to 9 percent of SSA countries' budgets on average and rendered losses of 2 to 5 percent of economic activity. Estimates indicate that adapting to climate change will cost Sub-Saharan Africa between US $ 30 billion and US $ 50 billion per year over the next decade, 2 to 3 percent of the region's GDP. The impact on the poor would be most severe, as climate change harms crop yields and hence food supply and exacerbates food insecurity (World Bank 2025).

Fiscal and monetary policies of Uganda have yielded sustained macroeconomic stability and impressive economic growth for the last two decades. However, these gains are getting eroded as the country continue to grapple with the distortionary effects of climate change; like destruction of public infrastructure[1], loss of economic output and reduced productivity of labour in the production process (Craighead, 2017 and USaid, 2012). These

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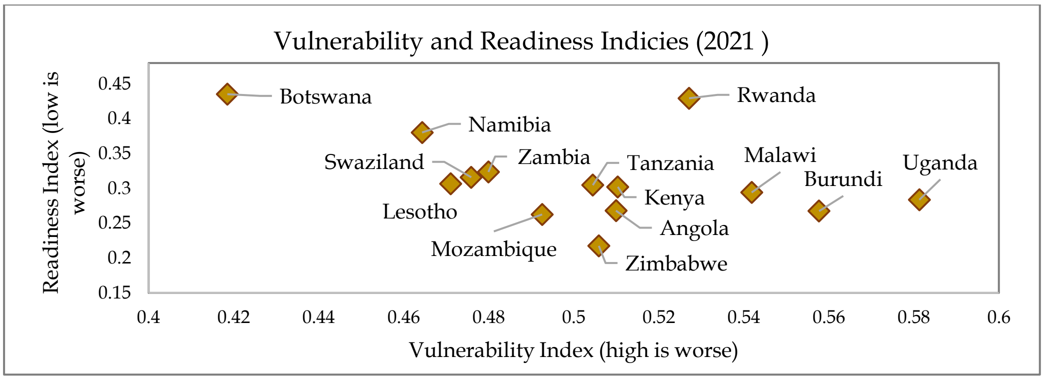
[1] According to the Ministry of Works and Transport (MoWT) roads due for maintenance are increasing and the budget required to clear the road maintenance backlog rose from USD 1,154 million in FY 2019/20 to USD 1,161 million in FY 2020/21. The stock of roads due for maintenance is growing and largely driven by increased depreciation rates caused by adverse weather.

distortionary effects have increased fiscal policy drudgery in tackling unemployment, poverty and effectiveness of service delivery.

Climate change affects fiscal policy outcomes through two impact channels. First, the physical damages on the economy through the impacts of climate related events like floods, storms, heat waves, drought, wild-fires, mudslides, rising temperatures and changes in precipitations, which impact on economic output and associated government revenues. The second impact pathway results from the adoption of climate policies (like carbon tax ad subsidy), technology advancements and consumption patterns that need to be abided with to attain a green economy (carbon reducing) and to meet Nationally Determined Contributions (NDC) under the legally binding international treaty on climate change (The 2015 Paris Agreement). Under this treaty, Uganda committed to reduce emissions by 24.7 percent by 2030.

The current structure of the Ugandan economy holds about three quarters of the labour force employed in agriculture; which is largely rain-fed, and hence making livelihoods highly vulnerable to the adverse weather events.. The ND-GAIN[2] annual data publication shows that Uganda has higher vulnerability to climate change shocks and lower scores for readiness to respond compared to peer states in the East and Southern Africa (Figure 1).

Figure 1: Vulnerability and readiness Indecies for 2021



Source: Based on data from Notre Dame Global Initiative (ND-GAIN)

Uganda's high level of vulnerability to adverse weather events strains fiscal policy through erosion of tax revenue effort and increasing expenditures related to the aftermath of these climate shocks. In the recent five years, Uganda government increased allocations to social transfers to support affected households and allocated more financial resources to the reconstruction of public infrastructure like roads washed away by floods and mudslides. Most of these emerge as supplementary expenditures financed through re-allocations from other budget priorities. These new spending pressures have scaled-up fiscal deficit (including grants) to 7.4% of GDP in FY 2021/22 against the East African Community (EAC) commitment target of 3% (MoFPED, 2022). The combination of climate related spending pressures

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[2] Notre Dame Global Initiative (ND-GAIN) publishes annual data on vulnerability and readiness for countries. This is under the University of Notre Dame.

with the COVI-19 shock and Russia-Ukraine conflict have posed fiscal policy management challenges. Consequently Uganda's debt-to-GDP ratio increased to 48.4% in FY 2021/22 against a sustainability threshold of 50%. Economic growth fell to below its potential of 6%with trickle-down effects on inclusiveness manifested in form of increased exposure to unemployment, poverty and inequality.

Reversing the distortionary effects of climate change on fiscal policy requires an empirical assessment to identify the main climate change impact pathways to fiscal policy outcomes to guide the choice of policy options that would reverse the adverse trends.

This paper assesses the magnitude and direction of impact of fiscal policy options aimed at mitigation and adaptation to climate change damages using a Dynamic Stochastic General Equilibrium (DSGE) model. The model is used to analyse the economy-wide macroeconomic effects of climate damages and the policy options to cushion the economy against the associated damages.

1.2 Objectives of the study

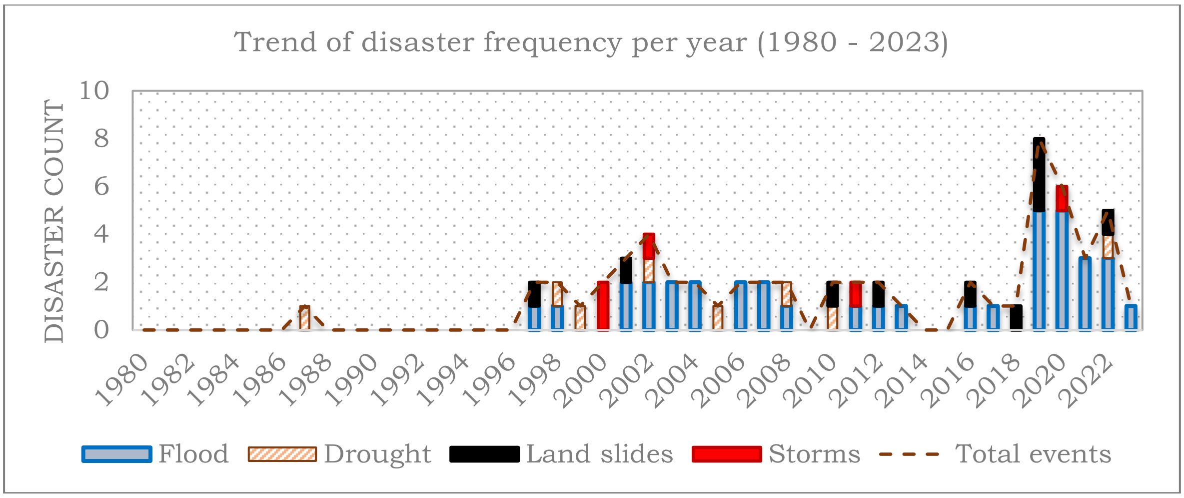
The main objective of this study is to identify and quantify options for hedging fiscal policy against the adverse effects of climate change in Uganda. The paper compares adoption of fiscal policy aimed at subsidising clean energy, investing in climate resilience infrastructure (adaptation) and provision of elief to the affected households. To address the above objective, the paper will be guided by the following specific research questions;

i. What are the main impact pathways through which climate damage externalities affects the effectiveness of fiscal policy in Uganda?
ii. Does climate damage externalities affect inclusive growth in Uganda?
iii. What are the plausible policy options that can rejuvenate inclusive growth and hedge Uganda's fiscal policy against the distortionary effects of climate change?
iv. Can transitioning to clean energy restore the effectiveness of fiscal policy in Uganda?

1.3. Climate change disasters and trends of emissions in Uganda

Natural disasters: In the last three decades, Uganda has faced a perpetually increasing frequency of natural disasters. Majority of these are floods, followed by the land slides, drought lastly storms as shown in Figure 1. The frequency of floods occurrences has a direct impact on damages to infrastructure which potentially dampen economic output and the associated tax revenues which feeds into fiscal deficit and debt dynamics. It is on this basis that that this paper use an environmental DSGE to assess the pathways through which climate change affects macro-fiscal outcomes and policy option to hedge the economy against these damages.

Figure 1: Trends of frequency of disasters in Uganda



Greenhouse gas emission trends: In 2015, Uganda signed the Paris agreement and thus committed to reduce emissions by 24.7 percent under the Nationally Determined Contributions (NDC). Contrary to this commitment, Uganda's emissions trend show an increasing trajectory over years; increasing from 33,330 Gg in 1995 to 94,650 Gg in 2017 (see Figure 2). Majority of these emissions are from Agriculture, Forestry and other Land Use (AFOLU); followed by waste and energy emissions. The AFOLU emissions are largely from land conversion (forestry to grassland and cropland) as shown in Figure

Figure 2: Trends of greenhouse gas (GHG) emissions

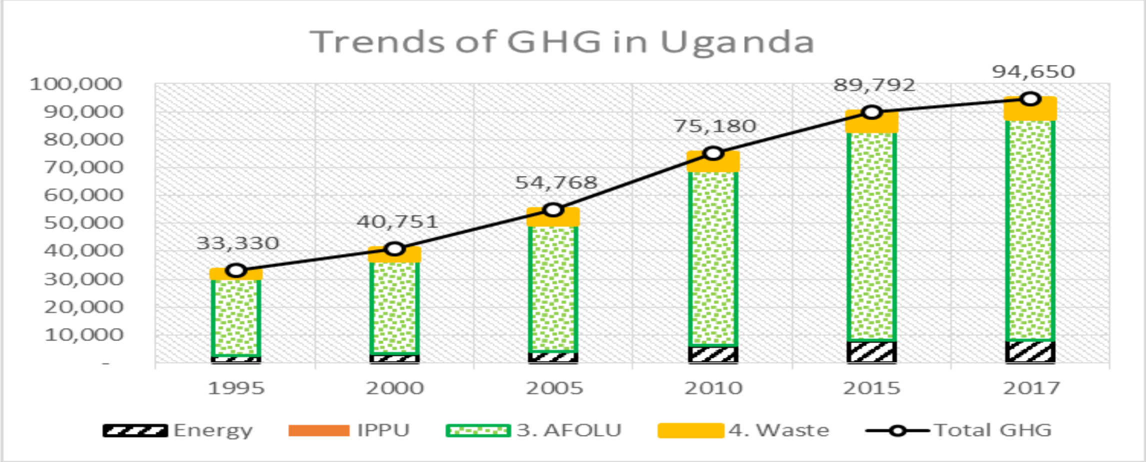


Table 3: Composition of energy emissions

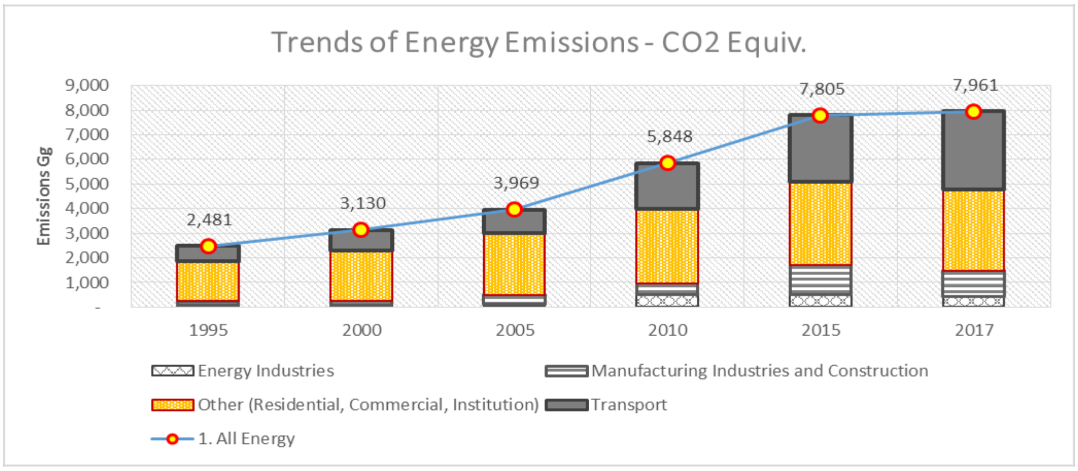
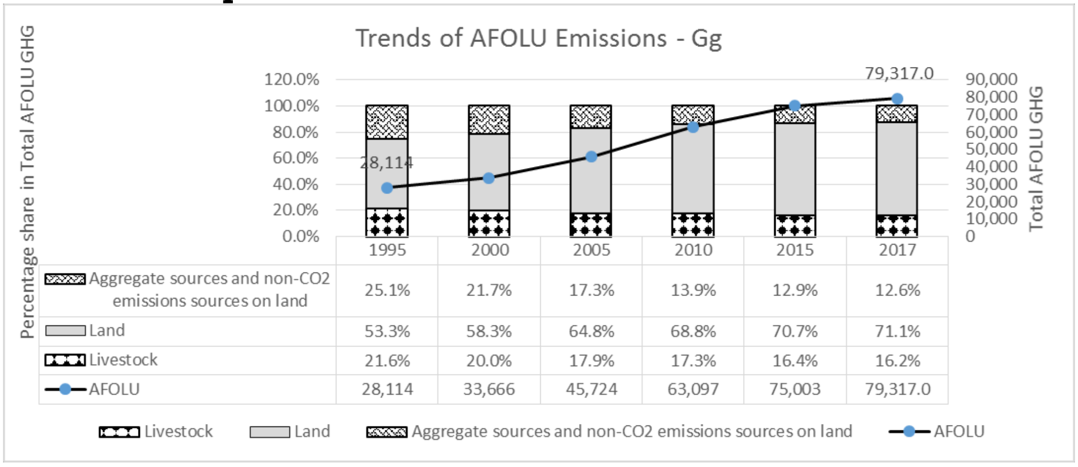


Table 4: Composition of AFOLU emissions



	1995	2000	2005	2010	2015	2017
▨ Aggregate sources and non-CO2 emissions sources on land	25.1%	21.7%	17.3%	13.9%	12.9%	12.6%
▭ Land	53.3%	58.3%	64.8%	68.8%	70.7%	71.1%
▦ Livestock	21.6%	20.0%	17.9%	17.3%	16.4%	16.2%
● AFOLU	28,114	33,666	45,724	63,097	75,003	79,317.0

2.0 Literature review

Climate change poses significant challenges to macroeconomic stability, public finance, and sustainable development, particularly in developing economies like Uganda. In response, a growing body of literature has sought to examine the macro-fiscal implications of climate damages, the role of adaptation, and the pathways for clean energy transitions using dynamic macroeconomic models. Among these, Dynamic Stochastic General Equilibrium (DSGE) models have gained prominence for their ability to capture the interactions between economic shocks, policy responses, and environmental dynamics within a coherent, forward-looking framework. This literature review explores existing empirical and theoretical studies that have applied DSGE and related models to analyze climate change, fiscal policy, and clean energy transitions globally and in Uganda, highlighting key findings, methodological approaches, and existing gaps that this paper seeks to address.

A growing body of literature employs Dynamic Stochastic General Equilibrium (DSGE) models to assess the macroeconomic and environmental effects of climate-related policies. Mintah (2024), using a climate DSGE model for Ghana, found that although Ghana contributes minimally to global emissions, it suffers significant climate-related damages. The study concluded that positive environmental policies can reduce emissions by promoting clean energy transitions, yielding welfare benefits. However, it also noted that positive monetary shocks might offset these gains through welfare losses, advocating for a balanced approach between environmental sustainability and economic growth. Similarly, Bukowski and Kowal (2010) demonstrated that investments in clean energy considerably reduce emissions in Poland, reinforcing the importance of clean energy adoption as a mitigation strategy.

In the context of China, Lei et al. (2023) applied a DSGE framework to examine emission reduction policies within the manufacturing sector. Their findings revealed that carbon taxes negatively affect sectoral output, while government spending on emission reduction offers short-term economic gains but turns detrimental in the long run. The authors recommend adopting a revenue-neutral recycling mechanism for emission tax revenues, combining sector-specific taxation with reduced public spending on emissions control. In addition, Khan et al. (2015) investigated the relationship between carbon emissions and business cycle fluctuations in the U.S. economy. They found that emissions decline during unanticipated economic shocks and rise during anticipated ones, highlighting the cyclical nature of emissions and macroeconomic activity.

In Morocco, Abdelhamid et al. (2025) assessed the macroeconomic impacts of a carbon tax using a DSGE model. The study confirmed that while carbon taxes effectively reduce emissions, they simultaneously depress economic output, curtail investment, and increase inflation, particularly in carbon-intensive sectors. Sectors with lower emission intensities demonstrated greater resilience and a faster recovery. Focusing on open economy dynamics, Chan (2019) employed an environmental DSGE model and established that higher environmental taxes suppress economic output. The study recommended that environmental taxes should be dynamic, adjusting in response to macroeconomic shocks, particularly reducing tax rates following positive total factor productivity (TFP) shocks.

Holtemöller and Sardone (2024) developed a two-sector DSGE model distinguishing between clean and dirty capital to evaluate optimal monetary policy under emission tax shocks. Their results indicate that emission taxes distort relative prices of clean versus dirty capital, impacting the effectiveness of conventional monetary policy. The authors advocate for a modified Taylor rule that incorporates welfare considerations alongside emission reduction objectives.

Within Uganda, several studies have assessed the socio-economic and macro-fiscal implications of climate and environmental policies. GiZ (2023) evaluated the impacts of Uganda’s energy transition and concluded that expanding clean energy access offers socio-economic and environmental benefits. The study noted, however, that such a transition entails substantial investment costs that should be met through government funding and international support.

Regarding, carbon tax, Nakijoba and Bulime (2023) examined Uganda's green growth sustainability and recommended implementing an environmental tax to internalize environmental externalities. They also emphasized the need for fiscal policies supporting private-sector green investments. Similarly, Lakuma et al. (2023) applied a dynamic Computable General Equilibrium (CGE) model to analyze sustainable, inclusive, and environmentally responsive debt in Uganda. Their findings indicate that public debt financing promotes reliance on biomass and fossil fuels, exacerbating climate challenges. They advocated for the introduction of a carbon tax to encourage clean energy adoption.

Regarding adaptation in Uganda, Hisali et al. (2011) identified socio-economic factors such as household head age, credit access, and land tenure as critical constraints to adaptation in Uganda. Cooper and Wheeler (2015) called for stakeholder collaboration to enhance adaptation effectiveness, while Echeverría et al. (2016) expanded the discourse by urging adaptation efforts to extend to fisheries, forestry, energy, and health sectors in Uganda.

The choice of DSGE modelling in climate and fiscal policy analysis is informed by their robust capacity to capture the interactions between macroeconomic shocks and policy responses. DSGE models have been extensively applied in diverse areas such as monetary policy and exchange rate volatility (Gali and Monacelli, 2005), oil price shocks (Soto and Medina, 2005), monetary policy and welfare (De Paoli, 2009), optimal monetary policy frameworks (Corsetti and Pesenti, 2005), and price dynamics (Benigno and Benigno, 2003).

DSGE models have increasingly been applied in Uganda to investigate various macroeconomic shocks. Okot (2020) used a DSGE model to evaluate the effects of extreme weather on GDP and inflation, concluding that adverse weather events depress output and raise prices. Anguyo et al. (2020) applied a regime-switching DSGE model to assess financial frictions, finding that model parameters shift under different economic regimes, with the regime-switching framework outperforming constant-parameter models in forecasting accuracy. Musil et al. (2018) assessed the benefits of coordinating monetary and fiscal policy through a DSGE model, finding positive macroeconomic dividends. Bwire et al. (2018) examined the effects of asset market participation and wage rigidity on monetary policy effectiveness, concluding that enhancing financial market access and promoting wage flexibility would improve policy outcomes.

Environmental DSGE models in Uganda have focused on public investments and fiscal responses to natural resource inflows. Kopoin et al. (2015) evaluated the interplay between public investments, oil revenues, and fiscal policy, recommending gradual public investment scaling to mitigate macroeconomic distortions. Similarly, Zeufack et al. (2016) advised that 55–85% of oil revenues be allocated to public investment to maximize long-term economic and environmental gains.

The application of a DSGE model in this study builds upon, but distinctively extends, its previous uses in Uganda. Unlike earlier works that have predominantly focused on either adaptation or mitigation in isolation, this paper integrates both dimensions within a unified macroeconomic framework. Specifically, the model is structured to assess how clean energy transition policies—through the introduction of an emission tax—can be used to finance climate adaptation measures, such as enhancing the resilience of infrastructure to climate-induced damages. Additionally, the model incorporates a comparative analysis of alternative revenue recycling options, including subsidies for clean capital investment and household rebates. A review of existing literature reveals that, to the best of our knowledge, this is the first application of a DSGE model in the Ugandan context to simultaneously integrate these features.

3.0 THE METHOD

3.1 An Environmental DSGE Model

To address the above research question, we propose to an environmental Dynamic Stochastic General Equilibrium (DSGE) model, composed of firms, Ricardian and rule of thumb households, government, and monetary policy institution. We modify the standard DSGE model to include energy sector and the climate related damages on capital stock and Total Factor Productivity (TFP) as specified following Hashimoto and Sudo (2022) and Carattini et. al., (2021) and Bwire *et. al.,* (2025). In general terms, we assume a small open economy, in that the actions of domestic economic agents can not affect neither the international commodity prices nor the foreign interest rates. We distinguish firms into two categorises; those that produce intermediate goods and perfectly competitive firms that transform these intermediate goods into final goods. The economy uses two types of goods including domestic and imports. The setting of domestic prices is assumed to follow Calvo (1983), thus are set with rigidity. We use the “Taylor rule” to capture the central bank’s monetary policy decisions. Within the model, decisions on supply of labour, consumption quantity and the share of imported commodities in the consumption basket are made by households. For ease of developing the baseline DSGE model, we assume perfect international financial integration. The baseline model blocks will be built as follows.

3.1.1 Production, energy and climate damage functions

We follow Hashimoto and Sudo (2022) and to modify the standard DSGE production functions to allow climate related weather events to have damages on capital stock and distort Total Factor Productivity (TFP). To impose emission tax, we split capital into dirty and clean capital stocks following Holtemöller and Sardone (2024) and Economides and Xepapadeas (2019); where we assume dirty capital produces emissions and clean capital is emission free. Carbon emissions and carbon tax are incorporated in the model following Carattini et. al., (2021).

3.1.1.1 Production and damage functions – clean and dirty capital

The model is built in such a way that domestic goods are produced intermediate producers who produce the semi-finished goods and the perfectly competitive retailers firms who use the intermediate goods to produce final goods. We assume that the intermediate producers operate in monopolistic competitive markets and use labour and capital as factor. For a harmonistic baseline model we assume that intermediate producers follow the Calvo approach of setting prices for final goods and these firms are infinite using similar production technology. The production function for intermediate producers is demonstrated below.

$Y_t = \frac{A_t}{\Omega\_tfp_t}(u\_clean + fK\_clean_t^{eff})^{\alpha 1}(u\_dirty + fK\_dirty_t^{eff})^{\alpha 2}L^{1-\alpha 1-\alpha 2}$ ..... (1)
And $u = \psi r_t^k$ .... (2)

We model climate change damages using direct damage function ($D(T_t)$) that reduces the effective capital stock (K_t^{eff}).

$K\_clean_t^{eff} = (1 - D(T_t, \vartheta))K\_clean_t$. .... (3)
$K\_dirty_t^{eff} = (1 - D(T_t, \vartheta))K\_clean_t$ ....(4)

$D(T_t, \vartheta) = \frac{\Psi T_t^2}{1+\phi T_t^2} + \vartheta_{dmg,t}$ ....(5)

$\Omega\_tfp_t = \exp(s_{dmg}\varphi_{dmg_t})$ .... (6)
$\varphi_{dmg_t} = \rho_{dmg}\vartheta_{dmg,t-1} + dmg_t$ .... (7)
$\vartheta_{dmg,t} = \rho_{dmg}\vartheta_{dmg,t-1} + dmg_t$ .... (8)

Where, Ω_tfp_t is the climate induced damage on Total Factor Productivity (TFP); φ_{dmg_t} is the direct damage shock on capital by extreme weather event; A_t is the Total Factor Productivity (TFP); Ω_tfp_t is the flood induced changes in TFP which is a function of the product of a constant scaler (s_{dmg}) concerning climate induced changes in TFP and the climate induced deterioration of productivity ($\varphi_{dmg,t}$) that follows an AR(1) process where $\rho_{dmg} \in (0,1)$. $K\_clean_t^{eff}$ and $K\_dirty_t^{eff}$ are capital stocks after climate damage induced depreciation. This is determined in the capital accumulation function. Then, ψ controls cost related to capital utilization; r_t^k is the nominal rental rate for capital and thus u is the intensity of utilization of capital. $\psi(u)$ is a convex function, meaning that if you increase the utilization of capital, it will depreciate more. In addition to impact on productivity and depreciation of capital stock, adverse weather can also affect the intensity of capital utilisation (u).

Then, $D(T_t, \vartheta)$ is the direct damage on existing capital stock by climate change adverse weather events like floods or storms. Unction if a function of changes in temperature (T_t) and extreme weather events shocks ($\vartheta_{dmg,t}$). The evolution of clean and dirty capital is as follows.

$K_{clean,t} = (1 - \delta)K_{clean_{t-1}} + Inv_{clean,t}$ .... (9)

$$K_{dirty,t} = (1-\delta)K_{dirty_{t-1}} + Inv_{dirty,t} \quad \text{..} (10)$$

Where, δ refers to the depreciation rate. Then, the investment function with investment adjustment costs is specified as follow;

$$(1+\beta)inv_t = \beta E_t inv_{t+1} + inv_{t-1} + \varphi q_t \quad \text{...} (11)$$

The respective Tobin's Q of capital stock is specified as follows;

$$q_t = \beta(1-\delta)E_t q_{t+1} + [1-\beta(1-\delta)]E_t r_{t+1}^k - (i_t - E_t \pi_{t+1}) \quad \text{...............................} (12)$$

Where; inv_t is investment; q_t is the Tobin's Q of capital stock and φ is captures the adjustment costs for investment. Thus φq_t captures sluggishness in investment.

3.1.1.2 Clean energy policies - Carbon tax

We follow Economides and Xepapadeas (2019) to include the energy sector in the DSGE model. We assume firms use two types of capital; first the dirty capital that uses fossil fuels and biomass for energy and clean capital that uses green energy (with less or no emissions). We follow Carattini et. al., (2021) and Holtemöller and Sardone (2024) to include the carbon emissions and the respective pigouvian tax to the model, as a policy tool for transitioning to clean energy. Carbon emissions and the respective tax revenues are derived as follows.

$$Emissions_t = (1-\gamma_t)\Psi(K_{dirty,t}) \quad \text{...} (13)$$

$$Tax_t^e = \tau_t^{carbon} * Emission_t \quad \text{..} (14)$$

Where γ_t refers to the abatement effort or fraction of the emissions abated; Ψ is the emission intensities per unit of dirty capital used in the production process; Tax_t^e carbon tax revenue; τ_t^{carbon} is carbon tax rate and $Emissions_t$ refer to emission from the use of dirty capital.

3.1.2 Households

In this model, we adopt two categories of households including the Rule of Thumb (ROT) and the Ricardian optimising hopuseholds; and these make decision on supply of labour to firms to earn wages. In regard to welfare, optimising households invest in riskless bonds in the financial market and derive their utility from consumption and disutility from supply of labor to firms. Only the ricardian (otpimising) households make intertemporal consumption decisions. The Rule of Thumb housheolds (ROT) consume all their earnings in the currrent period. To differentiate optimising households, we index following [0,1], where the proportion of households with a consumption pattern that follows the permanent income hypothesis is represented by the fraction $[0, \lambda]$ as specified by Furlanetto (2011). We set the model in such a way that households maximise utility subject to a budget constraint as demonstrated by Gali and Monacelli (2005); Bernanke, et. al. (1999) and Furlaneto (2011). We estimate the welfare function as a discounted lifetime utility of the representative household following Uhlig (1999), Schmitt-Grohé and Uribe (2004) and Galí (2015) who represent the household problem as a labour-leisure trade-off.

$$E_0 \sum_{t=0}^{\infty} \beta^t e^{gt} \left[\frac{C_t^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} - \frac{\zeta_L}{1+\sigma_L} \left(L_t^{1+\sigma_L} \right) \right] \quad \text{..} \quad (15)$$

Where, g_t denotes the demand shock; $1/\sigma$ is the intertemporal elasticity of substitution that governs how much utility a household loses by supplying labour; σ_L refers to the price elasticity of labor supply, ζ_L is the disutility of labour which determines how much utility a household loses from supplying labour. C_t is consumption; β^t is the discount factor and the utility function in the square brackets; L_t is leisure or labour. The budget constraint for Ricardan households is;

$$P_t(C_t^o + I_t^o) + \frac{1}{R_t} B_{t+1}^o + P_t T_t^o = W_t L_t^o + R_t^k K_t^o + B_t^o + D_t^o \quad \text{............................} \quad (16)$$

The ROT households face the following budget constraint;

$$P_t C_t^r = W_t L_t^r - P_t T_t^r \quad \text{...} \quad (17)$$

Where; C_t^o and C_t^r denote consumption for optimizing (Ricardian) and ROT households; I_t^o refers to investment; R_t is gross nominal interest rates; B_{t+1}^o is quantity of one period nominal bonds bought at the beginning of the period; T_t^o refers to lump-sum tax paid; D_t^o is dividends received from ownership of firms; $R_t^k K_t^o$ refers to capital income. Labor income for optimizing households is denoted by $W_t L_t^o$ and labor income for ROT households is denoted by $W_t L_t^r$.

The first order condition of the above maximization problem derives the optimal level of consumption. Households choose the composition of the consumption basket in regard of domestically produced commodities ($C_{H,t}$) and imported commodities ($C_{F,t}$). We model this combination using a Constant Elasticity of Substitution (CES) shown below.

$$C_t = \left[(1-\alpha_c)^{\frac{1}{\eta_c}} (C_{H,t})^{1-\frac{1}{\eta_c}} + (\alpha_c)^{\frac{1}{\eta_c}} (C_{F,t})^{1-\frac{1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}} \quad \text{...................................} \quad (18)$$

Where; α_c refers to the share of imported commodities in the consumption basket and η_c denotes the elasticity of substitution between domestic ($C_{H,t}$) and imported ($C_{F,t}$) commodities.

The Euler equation for consumption of Ricardian (C_t^o) and Non-Ricardian (C_t^r) households is presented below;

$$C_t^o = \frac{1}{(1+h)} C_{t+1}^o + \frac{h}{(1+h)} C_{t-1}^o - \frac{(1-h)}{(1+h)} \sigma\left(i - E\pi_{t+1}\right) \ldots\ldots\ldots\ldots\ldots\ldots (19)$$

$$C_t^r = (1-\lambda) * (L_t + rw) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

Where rw_t refers to real wage; $E\pi_{t+1}$ is expected inflation, h is habit in consumption and λ is the proportion of Ricardian or Optimizing households. Thus the Ricardian and Non-Ricardian consumptions are aggregated using the function below;

$$C_t = \lambda C_t^o + (1-\lambda) C_t^r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

3.1.3 Welfare computation

We use the welfare function above to compute the equivalent and compensating variations; following Perloff (2014). The two measures as equivalently used where; equivalent variation (EV) captures the percentage increase in consumption in the policy world needed to make the agent as well-off as in the baseline. Then, compensating variation (CV) captures the percentage increase in in consumption in the baseline needed to make the agent as well off as in the policy scenario. We follow Perloff (2014) to compute these measures as;

$$EV = \left(\frac{V_1}{V_0}\right)^{\frac{1}{1-\sigma}} - 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

$$CV = \left(\frac{V_0}{V_1}\right)^{\frac{1}{1-\sigma}} - 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

Where V_0 is baseline utility and V_1 is utility after the shock. Ten parameter σ determines the risk aversion.

3.1.3 The Law of one price

We assume the law of one price to allow the model to compute prices for foreign imported goods and domestic goods. Under this, the consumer price index is dependent on the nominal exchange rate and thus we compute the price for imported commodities as a multiple of nominal exchange rate (e_t) and import prices in foreign currency (P_t^*). Then, real exchange rate (RER) is the ratio of foreign and domestic prices (P_t). These are demonstrated below.

$$P_{F,t} = e_t P_t^* \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

$$RER_t = \frac{e_t P_t^*}{P_t} = \frac{P_{F,t}}{P_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

3.1.4 Phillips curve and wage inflation

The prices of home goods are defined by the Philips curve below.

$$\pi_{H,t} = \left(\frac{\beta}{1+\beta\chi_p}\right) E\pi_{H,t+1} + \left(\frac{\chi_p}{1+\beta\chi_p}\right)\pi_{H,t-1} + \left(\frac{\kappa_p}{1+\beta\chi_p}\right)\left[\alpha r_t^k + (1-\alpha) rw_t - a - (P_{H,t} - P_t)\right] \quad \text{...........} \ (26)$$

Equation (26) is the Phillips curve for domestic prices. The wage inflation is captured by the Phillips curve for wage inflation shown below.

$$\pi_t^w - \chi_w \pi_{t-1} = \kappa_w \left(mrs_t - rw_t\right) + \beta\left(E_t \pi_{t+1}^w - \chi_w \pi_{t+1}\right) \quad \text{..................................} \ (27)$$

$$\kappa_w = \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w(1+\varepsilon_w\sigma_L)} \quad \text{and} \quad \kappa_p = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$$

Where, rw_t is real wages; mrs_t refers to marginal rate of substitution between consumption and labor, θ_w is calvo's parameter of wage rigidities; χ_w is the degree of indexation of wages to past wage inflation; χ_p is the degree of indexation of wages to past inflation; ε_w is elasticity of substitution among labor supply of households; σ is the inverse of the Frisch elasticity of labor supply. Under flexible wages, the real wages (rw_t) is equivalent to the marginal rate of substitution between labor and consumption (mrs_t). However, with wage rigidities, rw_t and mrs_t defer and are specified as follow.

$$mrs_t = \sigma_L L_t + \frac{(C_t - hC_{t-1})}{\sigma(1-h)} \quad \text{and} \quad rw_t = \sigma_L L_t + \frac{1}{\sigma} C_t \quad \text{....................................} \ (28)$$

3.1.5 Imperfect exchange rate pass-through

The mode captures the impact of foreign prices on domestic prices using the imperfect exchange rate pass-through; that is the equation for inflation of imported goods as demonstrated below.

$$\pi_{F,t} = \left(\frac{\beta}{1+\beta\chi_F}\right) E\pi_{F,t+1} + \left(\frac{\chi_F}{1+\beta\chi_F}\right)\pi_{F,t-1} + \frac{(1-\theta_F)(1-\beta\theta_F)}{\theta_F(1+\beta\chi_F)}\left[rer_t - (P_{F,t} - P_t)\right] \quad \text{..} \ (29)$$

Where; χ_F represents the degree of indexation of foreign goods; $\pi_{F,t}$ inflation for imported goods; θ_F is calvo's parameter for imported goods and $P_{F,t}$ is the price of foreign goods.

3.1.6 International risk sharing

We assume that complete markets for internationally traded securities; thus the ratio of marginal utility of consumption of the household in the domestic economy and the rest of the world is proportional to the real exchange. This assumption is extracted from Gali and Monacelli (2005). The adoption of this assumption implies that, the model built in such a way that it allows perfect international integration, where Uganda is able to insure away idiosyncratic shocks through the international financial market but cannot insure against aggregate shocks[3]. With this assumption, the function below holds;

$$\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\frac{1}{\sigma}}\frac{P_t}{P_{t+1}}\frac{e^{g_{t+1}}}{e^{g_t}} = \beta\left(\frac{C^*_{t+1}}{C^*_t}\right)^{-\frac{1}{\sigma}}\frac{P^*_t}{P^*_{t+1}}\frac{e_t}{e_{t+1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(30)}$$

Where the LHS of equation (30) is the Euler's equation for the domestic economy and the RHS of the equation is the Euler's equation for the foreign economy.

$\frac{e_t}{e_{t+1}}$ refers to the exchange rate adjustment.

The above parity condition can be written as follows;

$$\left(\frac{C^*_t}{C_t}\right)^{-\frac{1}{\sigma}}\frac{1}{RER_t}\frac{1}{e^{g_t}} = \left(\frac{C^*_{t+1}}{C_{t+1}}\right)^{-\frac{1}{\sigma}}\frac{1}{RER_{t+1}}\frac{1}{e^{g_{t+1}}} = \left(\frac{C^*_0}{C_0}\right)^{-\frac{1}{\sigma}}\frac{1}{RER_0}\frac{1}{e^{g_0}} = v \quad \ldots\ldots\ldots\ldots\text{(31)}$$

Thus the non-arbitrage condition $\left(\frac{C^*_t}{C_t}\right)^{-\frac{1}{\sigma}}\frac{1}{RER_t}\frac{1}{e^{g_t}} = v$ remains unchanged across all periods. The real exchange rate is determined in this equation. For instance, an increase in C^*_t would result into an appreciation of the real exchange rate to keep v constant.

3.1.7 Uncovered Interest Rate Parity (UIP) Condition and Balance of Payments

The model is built in such a way that we use the uncovered interest rate parity condition (UIP) to determine the nominal exchange rate. The domestic interest rate (i) is determined as a summation of foreign interest rate (i^*_t) and changes in nominal exchange rate (Δe_{t+1}) as shown below.

$$i = i^*_t + \Delta e_{t+1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(32)}$$

To make the net external debt position of the economy necessary in describing the equilibrium, we assume incomplete international financial markets.

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[3] Perfect international integration means that Uganda can freely trade financial assets (like bonds, equity, insurance contracts) with the rest of the world without restrictions, frictions, or capital controls. It has full access to international financial markets. Then, idiosyncratic shocks are shocks that affect only Uganda, not the global economy. For example: A drought affecting Uganda's agriculture, a local epidemic, or a sector-specific productivity drop. Lastly, aggregate shocks affect all countries simultaneously, for example, global financial crisis, worldwide oil price spike, pandemic like COVID-19, and climate change effects that hit all regions simultaneously. Because every country is affected, no country can insure against these via the international market.

We extend the UIP condition with an addition of the net external debt (b_t^*) to make net external debt affect interest rates. This makes debt a risk factor that can potentially increase the domestic interest rates. This brings in debt as a disincentive of endless borrowing as it impacts the cost of borrowing. The adjusted UIP equation shown below.

$$i = i_t^* + \Delta e_{t+1} + \zeta b_t^* \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (33)$$

The net external debt (b_t^*) is determined in the Balance of Payments (BOP) is specified below;

$$\begin{aligned} \frac{B^*}{Y} b_t^* = {} & \frac{B^*}{Y}\frac{1}{\beta}\left(i_t^* - \pi_t^*\right) + \frac{B^*}{Y}\left(\frac{1-\beta}{\beta}\right) rer_t + \frac{B^*}{Y}\left(\frac{1+\zeta}{\beta}\right) b_{t-1}^* \\ & + \frac{M}{Y}\left(m_t + rer_t\right) - \frac{X}{Y}\left(x_t + \left(P_{H,t} - P_t\right)\right) \end{aligned} \quad \ldots\ldots \quad (34)$$

Where; $\frac{B^*}{Y}$ is the share of foreign debt to GDP; ζ refers to the elasticity of the sovereign spread to external debt. The inclusion of the sovereign spread (ζ) that is sensible to the next external debt is key in ensuring that we have a stationary solution around the steady state. Furthermore, $\frac{X}{Y}$ is the share of exports to GDP; $\frac{M}{Y}$ is the share of imports to GDP and $\left(P_{H,t} - P_t\right)$ is the effect of relative prices.

3.1.8 Fiscal policy

We build the fiscal policy following Gali et. al., (2007) where the budget constraint is made of government expenditure (G_t), borrowing (B_t), and taxes (T_t) as shown below.

$$P_t T_t + R_t^{-1} B_{t+1} = B_t + P_t G_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (35)$$

Thus the fiscal constrain is specified as follows.

$$t_t = \emptyset_b b_t + \emptyset_g g_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (36)$$

and

$$g_t = \rho_g g_{t-1} + \epsilon_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (37)$$

$\emptyset_b$ and $\emptyset_g$ are positive constants

Where;

$$T_t = \lambda T_t^r + (1-\lambda) T_t^O + Tax_t^e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (38)$$

$$g_t = (G_t - G)/Y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (39)$$

$$t_t = (T_t - T)/Y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (40)$$

$$b_t = ((B_t/P_{t-1}) - (B/P))/Y \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (41)$$

The stock of public debt would accumulate following equation;

$$b_t = \frac{1}{\beta_c} b_{t-1} + G_Y . g_t + GADPT_Y . G_t^{adapt} + s_{clean} + Rebate_{hh,t} - \bar{\tau}_y^{ss} . \left(\tau_{y,t} - y_t\right) - \bar{\tau}_c^{ss} . \left(\tau_{c,t} - c_t\right) - \bar{\tau}_{co2}^{ss} . \left(\tau_{co2,t} + k_t^{dirty} + \gamma_{cons} co2_t\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (42)$$

$$FD_t = b_t - \frac{1}{\beta_c} b_{t-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (43)$$

The left-hand side (LHS) is government debt stock (b_t). The right-hand side (RHS) is composed of: $\frac{1}{\beta_c} b_{t-1}$: Previous period's debt grows at the inverse of the government's discount factor (equivalent to accruing interest if $\frac{1}{\beta_c} > 1$. Then $G_Y . g_t$ which is the government expenditure; $GADPT_Y . G_t^{adapt}$adaptation expenditure. Then, s_{clean} captures the subsidy for clean capital; $Rebate_{hh,t}$ refers to rebate of emission tax revenue to households in terms of transfers. The rebates are imposed in a way that ensures revenue neutral clean energy transition. We subtract tax terms; $\bar{\tau}_y . \left(\tau_{y,t} - y_t\right)$ represent direct taxes; $\bar{\tau}_c . \left(\tau_{c,t} - c_t\right)$ capture indirect taxes; whereas $\bar{\tau}_{co2}^{ss} . \left(\tau_{co2,t} + k_t^{dirty} + \gamma_{cons} co2_t\right)$ captures the taxes on emissions. Then, $\bar{\tau}_y^{ss}$, $\bar{\tau}_c^{ss}$ and $\bar{\tau}_{co2}^{ss}$ refer to steady state tax rates. Parameter γ_{cons} measures the emission intensity of consumption and FD_t denotes fiscal deficit.

3.1.9 Monetary policy

The model uses the Taylor Rule capture the monetary policy setting by the central bank. Following Gali et. al., (2007) and Bwire *et. al.,* (2025) we construct the Taylor rule where interest rate is a function of inflation differential (π), output diffrentials (y_t), previous interest rates (i_{t-1}) with a parameter (ρ) that represent the degree of interest rate smoothing. Then, ϕ_π is the Taylor rule response to inflation differentials and ϕ_y represents the response to output gap differentials. This is demonstrated below.

$$i_t = \rho_i i_{t-1} + (1 - \rho_i)\left[\phi_\pi \pi_t + \phi_y y_t + \phi_e e_t\right] + Z_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (44)$$

To capture the transmission of monetary policy to fiscal policy through induced deviations of output; we use the sacrifice ratio. This defines the output lost to have inflation reduced by 1 percent under the Taylor rule framework. We build the sacrifice ratio following Vukotic and Pancrazi (2016).

3.2 Calibration of the Model

The parameters of the Environmental DSGE are calibrated using the macroeconomic data for Uganda with supplementary coefficients from recent estimated DSGE parameters for Uganda. We also use the Social Accounting Matrix (SAM) and National Accounts (GDP expenditure) for Uganda to calibrate the steady state parameters. For the environmental and climate data; we use data collected from Uganda's Ministry of Water and Environment

(MoWE). The estimated parameters for our DSGE were mainly sourced from Ugandan scholars like Okot (2020), Anguyo et. al., (2020), and Zeufack *et. al.,* (2016).

Based on the baysian estimations of DSGE parameters by Okot (2020), we calibrate the discount factor, $\beta_c = 0.969$; the Intertemporal elasticity of substitution (IES) $\sigma = 0.895$ and Inverse Frisch elasticity of labor supply $\alpha_L = 2$. Then, the Calvo price stickiness for domestic firms θ_p is calibrated at 0.436; Price indexation to past inflation χ_p at 0.328; Calvo price stickiness for imported goods θ_f at 0.355; and indexation in foreign prices χ_f at 0.495. The Taylor rule response to inflation deviation ϕ_π is calibrated at 1.8104; Taylor rule response to output gap ϕ_y calibrated at 0.154 and the Taylor rule response to exchange rate ϕ_e is calibrated to 0.0231 following Anguyo et. al., (2020). The rest of the parameter calibrations and steady state values are shown in Table 1 and Table 2.

Table 1: Parameter calibration

Parameter	**Value**	**Description**	**Source**
λ	0.85	Share of Ricardian (optimizing) households	Okot (2020)
α_c	0.12	Share of imported goods in consumption	MoDPED, SAM** 2016/17
β_c	0.969	Discount factor	Okot (2020)
σ	0.895	Intertemporal elasticity of substitution (IES)	Okot (2020)
α_L	2	Inverse Frisch elasticity of labor supply	Okot (2020)
θ_p	0.436	Calvo price stickiness for domestic firms	Okot (2020)
χ_p	0.328	Price indexation to past inflation	Okot (2020)
ρ_{norm}	0.639	Interest rate smoothing parameter in Taylor rule	Okot (2020)
ϕ_π	1.8104	Taylor rule response to inflation deviation	Anguyo et. al., 2020
ϕ_y	0.154	Taylor rule response to output gap	Okot (2020)
ϕ_e	0.0231	Taylor rule response to exchange rate	Anguyo et. al., 2020
δ	0.025	Depreciation rate of capital	Okot (2020)
θ_f	0.355	Calvo price stickiness for imported goods	Okot (2020)
χ_f	0.495	Indexation in foreign prices	Okot (2020)
α_i	0.267	Share of imported goods in investment	National Accounts FY 2024/25 – UBOS***
$\bar{\tau}_y$	0.3	Steady-state tax rate on labor income	GFS (MoFPED)Policy Rate
χ_{wlfr}	3	labour disutility	Zeufack *et. al.,* (2016).
ϕ_{wlfr}	2	Inverse frisch elasticity of labour supply	Okot (2020

θ_{CO2}	1.172	Emissions per unit of dirty capital	Emission data (MoWE)* and SAM 2016/17

** Social Accounting Matrix (SAM) for Uganda. *** Uganda Bureau of Statistics (UBOS). * Ministry of Water and Environment (MoWE).

Table 2: Steady state values as percentage of GDP

Steady state ratios	**Description**	**Values**
I_Y	Share of investment in GDP	0.267
X_Y	Share of exports to GDP	0.184327
M_Y	Share of imports to GDP	0.20117
C_P/Y	Share of private consumption to GDP	0.619568
C_G/Y	Share of government consumption to GDP	0.130396
NX_Y	Share of net exports to GDP	X_Y- M_Y

Source: Calibrated using Uganda's National Accounts (GDP) for FY 2024/25

3.3 Scenario design

The simulations start with the climate change induced infrastructural damage scenario; which we design in form of an accelerated depreciation of capital stock. We then examine the macro-fiscal impacts of these climate damages. Thereafter, to safe-guard the macro-fiscal economy from such climate damages, we impose an emission tax on dirty capital to raise funds for either of the three policy options. First, to finance adaptation expenditures. Second, to subsidise clean capital investments and lastly, to finance relief expenditures to the affected households (rebate transfers to households). The results of these policy scenarios are discussed below.

4.0 Results

In this section, we discuss results of two scenarios. First, the impact of climate change damages on fiscal policy outcomes, inclusivity of growth and the general macroeconomic effects. We use fiscal deficit, debt accumulation and economic growth as the proxy for fiscal policy. The second scenario, imposes a carbon tax on dirty capital with revenue recycling options of either financing investments in adaptation, subsidising clean capital and rebates to households. We begin by discussing the pathways through which climate damages impact macro-fiscal policy in section 3.1. Then in section 3.2 we discuss the policy options of recycling emission tax revenues, including financing resilience of infrastructure (adaptation).

4.1 Pathways of climate damages to fiscal policy, and inclusive growth

The pathways through which climate change damages impact on the macro-fiscal policy outcomes are shown in figure 1(blue line). The results are depicted as deviations from the steady state.

Government revenues and expenditure pathway: change is through two main pathways; government revenues and expenditure. Figure 1 show that, climate damage induced damages on capital stock; dampens economic output (tax base); which reduces tax revenue collections and thus increase the budget deficit and debt accumulation. The other pathway to fiscal outcomes is the upward pressure on prices that increase government expenditure.

The rise in prices is because of the reduction of economic output against demand. Thus, the impact of climate damages on fiscal deficit is twofold, including the reduced tax revenue and inflated government expenditure. The aftermath of this, shows that the increased fiscal deficit increases public debt. The shocks that increase debt, risk making Uganda's debt to exceed the sustainability levels and worsen the fiscal deficit against the target set in the Charter for Fiscal Sustainability (CFR). This makes climate damages as one of the key sources of fiscal risks in Uganda's macro-fiscal management and compromises e fiscal policy credibility.

The interest rate channel: The third pathway of climate damages effects on fiscal policy is nominal interest rate channel. Figure 1 shows that, climate damages increase domestic prices and nominal interest rates. This increases the costs of domestic borrowing for fiscal operations. The climate induced surge of nominal interest rates risks increase cost of borrowing for the government widening the fiscal deficit.

Welfare pathway and inclusive growth: The results show that, climate induced damages affect fiscal policy through the reduction of household welfare. Figure 1 shows that, climate induced infrastructural damages would reduce household welfare as shown by the drop in the equivalent variation (EV)[4]; which is the amount of money needed to move the household's utility (from their baseline utility level) to their new level of utility (policy scenario) after a climate disaster damages. Figure 1 shows that welfare (equivalent variation) declines after the climate damage shock and this affects fiscal policy through increasing fiscal pressure in form of relief expenditures to the affected households. Such relief expenditures are in form of, cash transfers, food relief supplies, public health care and relocation of the affected people. Since, welfare losses raise political and social cost of fiscal inaction; climate damages create implicit fiscal risks for government; thus distorts fiscal credibility.

Figure 1: Infrastructural damages, adaptation and clean energy transition

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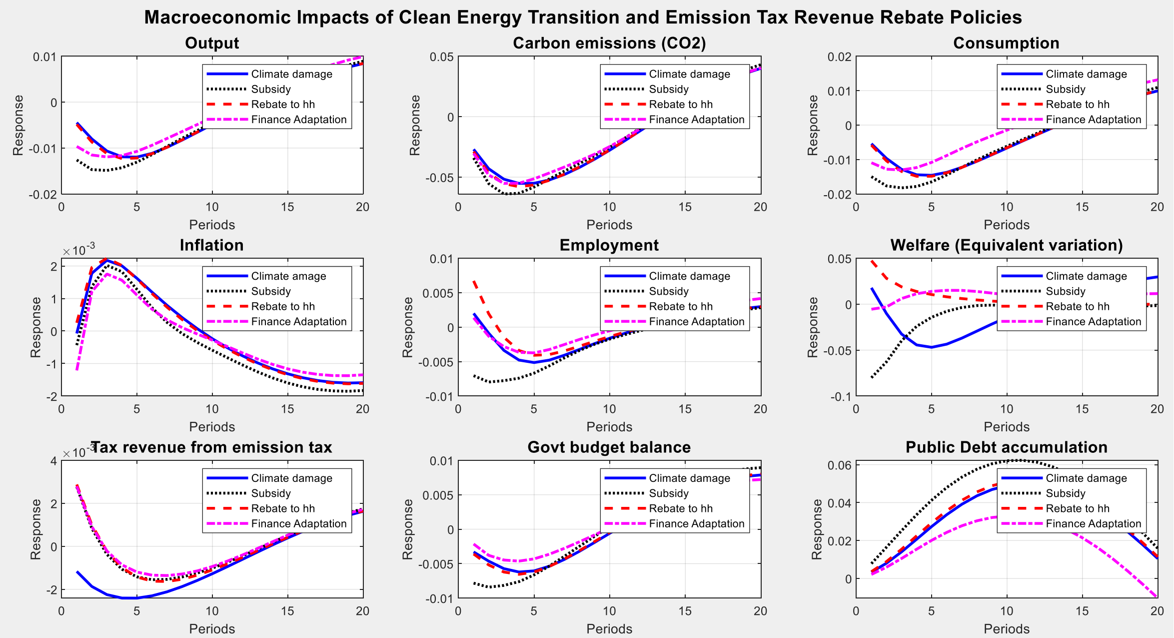
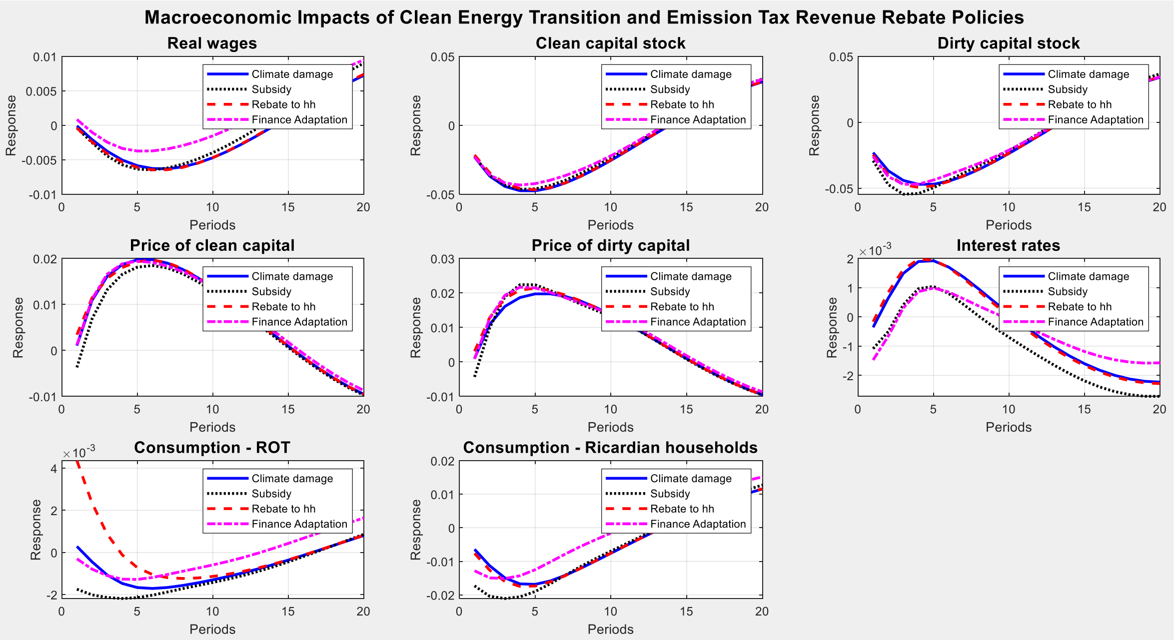
[4] This answers the question; How much money would you need to give (or take) to leave someone as well off as they were before the change?





4.2 Financing adaptation with revenue clean energy transition policies

To hedge the economy against the above macroeconomic distortions associated to climate change damages; there is need for investment in enhancing resilientpublic infrastructreto adapt to climate change shocks. However, financing adaptation poses a policy challenge. We analyse the option of financing adaptation with a tax on emissions ondirty capital used in the production process. We extend the analysis to compare revenue recycling with other policy options like; rebate subsidies to investments in clean capital, and rebates to households in form of direct transfers. This enables the paper to discuss the internal adaptation financing as well as transitioning to clean energy ispired by Uganda's commitment to the 2015 Paris Agreement.

Fiscal policy outcomes (debt and growth): The results in Figure 1 show that imposing a tax on dirty capital, reduces the damage of climate shock on governmnet revenues for all revenue recycling scenarios. However, tax revenue improves faster under the adaptation scenario; followed by the rebates to households and lastly subsidy to clean energy. This is also reflected in the budget balance (fiscal deficit) and debt accumulation outcomes; where pressures on debt increases created by the climate damage shock is reduced under the adaptation policy option. This is consistent with the findings of Deng (2015) & Aaheim et. al., (2009) who found that increasing resilience of public infrastructure improves the safe-guards of the macroeconomic stability against climate change disasters. On the other hand, the subsidy to clean capital policy option, worsens the debt accumulation above the climate damage scenario. Rebates to households; has minimimal impacts on the debt accumulation levels caused by the climate shock. In terms of economic growth, in the short run, adaptation and rebate subsidies to clean capital worsen the imapct of climate damage shock on output; however, in the medium term, using emission tax revenue to finance adaptation reduces the output losses caused by climate damages. This shows that, recycling emission tax revenues to financing adaptation, provides the best option to hedge fiscal deficit, debt accumulation and economic growth against the climate change shocks in Uganda. Based on these results; we assert that the adaptation scenario provides the best fiscal policy outcomes.

Welfare and inclusive growth: Raising taxes on dirty capital to finance safe-guards for household welfare (equivalent variation) provide differentitated impacts depending on the revenue recycling policy option adopted. Welfare improves highest in the short rum under the rebates to households; but this is surpussed by the adaptation financing in the medium term (Figure 1). However, subsidy rebates to clean capital worsens welfare losses from climate damages in the shortrun before improving in the medium term; although remains below the adaptation and household rebates in the short run. In terms of consumption, the non-Ricardian (Rule of thumb) households attain positive consumption under rebate transfers policy option; whereas the ricardian (optimising) households maximise welfare under the climate damage shock when the emission tax revenues are used for adaptation investments. In addition, rebate subsidies for clean capital worsens consumption for the ricardian and non-ricardian households. Following this, adaptation provides the best option for hedging consumption against climate change shocks. Similary, economic growth performs better under adaptation revenue recycling. Thus, we assert that, using emission tax revenues to finance adaptation provides the best policy option to hedge household welfare against shocks from climate change damages.

Inflation and Interest rates: Climate damages increase domestic prices due to the fall in output as shown in Figure 1. The climate induced deterioration of capital increases the margical costs of production (see price of clean and dirty captal in Figure 1); risk-averse investors demand higher returns for holding assets, thus adjusting the interest rates that affects the cost of government domestic borrowing. Secondly, the upward pressures on inflation makes the central bank to increase interest rates under the Taylor Rule[5] framework as shown in Figure 1. This increases the cost of domestic borrowing for the government of Uganda; thus worsening the fiscal deficit and debt burden. The results show that; adaptation and subsidy rebates to clean capital are the best in reducing upward pressures on nominal interest rates caused by climate damages. The revenue recycling policy options provide the best option to hedge the cost of government borrowing from interest increases caused by climate damage shocks.

Real wages and employment: Figure 1 shows that climate damage shocks reduce the real wages and employment. However, when emission tax revenues are recycled to finance adaptationthe loss to real wages is reduced. However, employment recovers above the baseline (positive change) under the rebate transfers to households scenario. Second to this policy option is the adaptation financing. It should be noted that; subsidy rebates to clean capital worsens the loss in employment in the short run before returning to the steady state in the medium term (see Figure 1).

Clean energy transition and emissions: The results show that climate change damages reduce the stock of both clean and dirty capital; which increases the price for these captail stocks (Figure 1). However, taxing emissions to finance adaptation reduces the distortionally effects of climate damages on the clean and dirty capital. Under the adaption, the transition to clean capital is negligibly small. However, the transitioning to clean capital improves when the emission tax revenues are used for subsidy rebates to households. This is shown by further deterioration of dirty capital stock and a reduction in climate damages on clean energy. Then, although climate damages reduce emissions flow following the fall in output; additional policy to tax emissions and use the revenues for subsidy rebates to clean capital reduces further the flows of emissions economic activity. The emission flows increases above the climate damage scenarion under the adaptation policy option of revenue recycling. Based on these results, we assert that using emission tax revenues to subsidise clean capital is the best revenue recycling policy option for reducing emissions and igniting the transition to clean energy.

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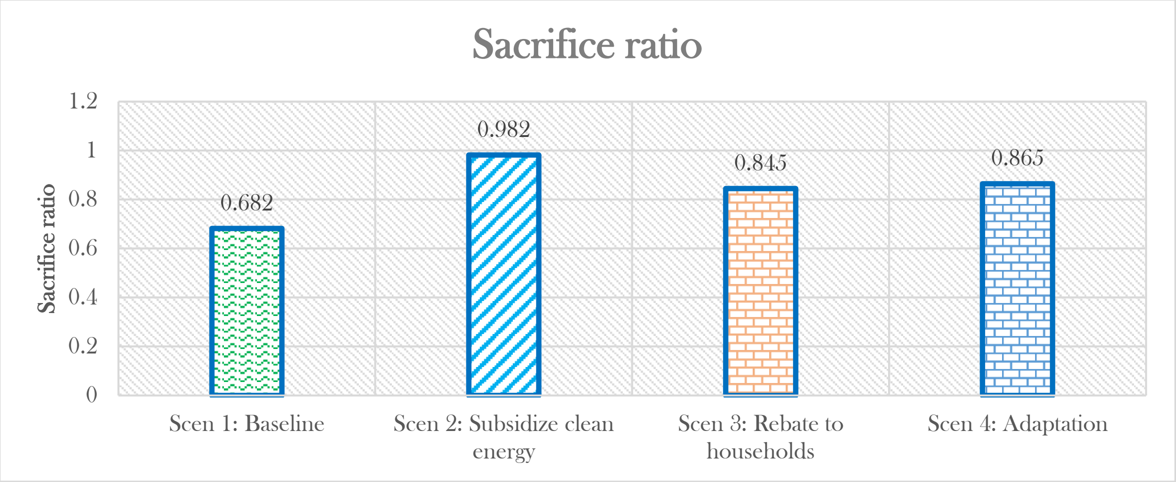
[5] The Taylor Rule is a monetary policy guideline that central banks can use to set short-term nominal interest rates in response to deviations of inflation from its target level and output (or GDP) from its potential level. Central Banks like Bank of Uganda do follow inflation targeting; thus use the Taylor Rule to set the nominal interest rates. This rule was first proposed by economist John B. Taylor in 1993, and has been popular in the implementation of monetary policy across the world.

4.3 Clean energy transition and the monetary policy cushions for fiscal policy

In this section we assess the impact of clean energy transition on the effectiveness of monetary policy in cushioning fiscal policy outcomes. When contractionary monetary policy is adopted, it constrains credit as well as aggregate demand which ignites a fall in tax revenue collections. And this introduces an upward pressure on the fiscal deficit and debt accumulation. We use the sacrifice ratio to capture the cost of reducing inflation in terms of lost output (or GDP)[6]. Thus, sacrifice ratio serves as an indicator of the effectiveness of monetary policy and the strength of monetary policy feedback to fiscal policy.

The results depicted in Figure 2 show that, the sacrifice ratio is highest under the scenario where emission tax revenues are used for subsidizing clean capital investment (0.982). This implies that, under this scenario, reducing inflation by 1 percentage point would result into a loss of economic growth by 0.982 percentage points. Second to this, is the scenario of financing adaptation, with a sacrifice ratio of 0.865. Lastly, the rebates transfers to households (0.271). All these are above the baseline sacrifice ration (0.682); we assert that carbon tax on dirty capital results into an increase in the sacrifice ratio. These finding show that; the cost of monetary policy in terms of fiscal policy (through reduced output and tax revenues) is highest under the scenario of subsidising clean capital and lowest rebate transfers to households as shown in Figure 2. The findings are in tandem with the conclusion of Holtemöller and Sardone (2024) who found carbon taxes to have pathways to the optimal monetary policy.

Figure 2: Sacrifice ratios for emission tax revenue rebate options



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[6] When a central bank tightens monetary policy to lower inflation (e.g. by raising interest rates), this measure reduces economic activity and increases unemployment in the short run. The sacrifice ratio quantifies this trade-off between disinflation and real output losses. Thus, the sacrifice ratio tells us how much cumulative real GDP must fall to permanently reduce inflation by 1 percentage point over the disinflation period.

5.0 Conclusion and recommendations

The findings of this paper show that the macro-fiscal impacts of transitioning to clean energy are dependent on the emission tax revenue recycling option that is chosen. The policy impacts are mixed. Subsiding clean capital is the best for reducing emissions and igniting transitioning to clean energy; making it the best policy option to attain Uganda's NDC commitments to reduce emissions by 24.7 percent by 2030. However, this policy option dampens economic output, consumption, employment, household welfare and increases the fiscal deficit and results in debt accumulation more than any other scenario. This confirms existence of transition risks to the adoption of clean energy transitions in Uganda. On the other hand, using emission tax revenue to finance adaptation provides the best outcomes for economic output, tax revenues, fiscal balance, debt accumulation, welfare, and real wages. Based on these mixed effects; we conclude that, there exist a trade-off between macro-fiscal management and clean energy transition policies. This calls for integration of climate change policies in macro-fiscal planning.

Based on the above findings, we recommend the extension of macro-fiscal policy tools to accommodate climate change policy analysis. This paper contributes to policy and academic debates by uncovering the interactions of climate change damages, adaptation policies and transitioning to clean energy with macro-fiscal outcomes. The paper assesses how clean energy policies like emission tax can be used to finance adaptation that shield the economy from exposure to climate damage shocks. Although the paper has covered some climate policies like carbon tax adopted in the domestic economy; it excludes the assumption that Uganda will potentially produce oil in the near future. Future scholars could assess the impact of such pigouvian emission taxes policy measures on Uganda's oil sector.

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