Climate change and central banking in Africa

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Abstract

Climate change poses significant challenges to country development and welfare across the globe with the effects of global warming leading to rising temperatures, increased frequency of extreme events and actions to limit the rise in emissions requiring structural changes in economies. Africa is expected to be more negatively impacted by climate change due to their dependence on climate vulnerable sectors, limited ability to adapt, and multitude of equally important developmental objectives. Opportunities, however, also exist for many countries in Africa given expected population increases, the need for new infrastructure development and the availability of abundant renewable and transition dependent resources. These climate induced changes in economies pose tangible risks to the financial sector and central banking functions of monetary policy and financial stability as they affect relative price adjustments, changes in balance sheets and broader economic activity. In this paper we explore how climate change affects economies within Africa and the implications of such changes for central banking in the region. A case study of South Africa is used to illustrate how existing models can be used to identify the key risks stemming from climate change and linked with traditional central banking models for monetary policy and fiscal stability assessment.

Key words: Climate change risks, economic modelling, fiscal stability, monetary policy, stress testing.

Introduction

Climate change poses significant challenges to country development and welfare across the globe with the effects of global warming leading to rising temperatures, increased frequency of extreme events and actions to limit the rise in emissions. Climate change risks have been generally grouped into two distinct categories, namely physical risks, and transition risks (TCFD, 2017).

Physical risk refers to the physical impact of long-term changes in temperature and precipitation (chronic physical risks), as well as the risks related to the increased frequency of extreme events (acute physical risks). Chronic physical risk impacts on the economy are therefore more likely to be felt in the medium to long-term as changes in climates compound over time as temperatures rise or precipitation declines. Chronic physical risks include water availability which has implications for energy and agriculture production, crop yields, health and productivity, and loss in biodiversity among others. Acute physical risks, while also having potential long-term impacts, also have short to medium impacts as the occurrence of an extreme event is uncertain, happens suddenly and can have large immediate impacts on for example productive capital assets and infrastructure. Physical climate impacts in developing countries will be more severe due to their dependence on climate vulnerable sectors (e.g. agriculture and tourism), limited ability to adapt, and multitude of equally important developmental objectives. According to the IPCC most countries in Africa will be disproportionately affected by climate change experiencing higher temperatures earlier than wealthier northern hemisphere countries, with higher compounding risks from reduced food security due to increased water stress and shortened growing seasons, increased heat related mortality and labour productivity loss, and sea level rise related flooding which will significantly increase the financial burden related to infrastructure damage and repairs. Impacts are projected to be widespread and severe in the absence of sufficient mitigation to limit global warming to 1.5°C (Trios et al., 2022).

Transition risks refer to economic, social, technological, regulatory, and geopolitical risks that arise from the shift to a low carbon economy. These risks are considered to be more imminent as policy implementation and changes in preference are already transpiring due to the lead times associated with the transition. A key transition for many countries will be shifting energy technologies from traditional fossil fuels to cleaner alternatives such as renewable energy. Coupled with transition risks are also opportunities that result from the development of new markets for materials needed for clean technologies key to the transition but also other markets such as carbon trading. Transitioning economies toward low carbon growth as well as increasing resilience to reduce the negative impacts of physical climate change require significant investments in new technologies and sectors.

Adam et al. (2023) reports a more recently developing third category of risk, namely liability risks. Liability risk, which is associated with physical and transition risk, refers specifically to legal liabilities companies or individuals may face because of losses caused by physical and/or transition risks. This type of risk is largely faced by financial services firms, such as the insurance industry. Liability risk essentially asks the question who is ultimately responsible for the costs associated with physical and transition risks.

The changes induced by climate change in both local and global economies and the shifts in resources required have implications for the financial sector and central banks. In this paper we explore how climate change affects economies within Africa and what the implications of such changes are for central banking in the region. Understanding the impacts of climate change is a crucial first step to understanding the potential impacts of climate change for central bank functions. In this paper we use the example of South Africa to identify the key risks stemming from climate change for monetary policy and fiscal stability.

Climate change risks in Africa

Physical risks are reported to be the primary risk across most of Africa given the faster change in climatic conditions, exposure to climate vulnerable sectors, less advanced infrastructure, and low capacity to adapt. On average near-surface air temperatures across the continent increased by 0.3°C per decade in the 1991-2022 period, compared with the 0.2°C increase experienced in the 1961-1990 period and the global average increase of 0.2°C. Temperature increases differed across the continent, ranging between 0.2°C per decade in Southern Africa and 0.4°C per decade in North Africa (WMO, 2023). Over the past three decades, Africa also experienced an increase in frequency and intensity of extreme events with 80 such disasters being reported in 2022 alone. These events included heavy rainfall, floods, tropical cyclones, droughts, heatwaves, wildfires, and sandstorms. The economic damages resulting from these events are estimated to be US$8.5 billion. GDP per capita in the region is reported to be 13.6% lower in the 1991-2022 period because of climate change (Trisos et al. 2022).

The IPCC (Trisos et al. 2022) projects continued increases in temperature across Africa with most countries expected to experience record high temperature climates earlier than wealthier countries further north. Rising temperatures, along with precipitation uncertainty and increases in extreme events will lead to broader and more severe negative impacts including lower economic growth, increased inequality and poverty, and reduced food production. The physical impacts of climate change have direct impacts on key sectors in Africa. These include agriculture, energy, and tourism.

Many countries in Africa are dependent on agriculture, particularly rainfed agriculture as a key economic activity. The IPCC (Trisos et al. 2022) reports that agriculture productivity in Africa has decreased by more than 30% since 1961 because of climate change – more than any other region in the world. Estimates indicate further declines in yields are expected with increasing water stress and shortening growing seasons also expected to negatively affect agriculture production and food systems. Thomas et al. (2022) estimates that in Southern Africa between 2020 and 2060, yields on rainfed maize – a key staple crop in many African countries – is likely to decrease by between 0.2% (low emissions) and 9.2% (high emissions) with the likelihood of extreme low-yield events increasing from 1-in-20-years to 1-in-3.5 years. Lower yields are also expected for other key crops such as dry beans, groundnuts, and soybeans. Enahoro et al. (2023) report significant crop area losses under climate change in West Africa that would result in an increased dependency on food imports. Specifically, suitable maize areas are estimated to decrease from the current 90% to between 15% and 43% depending on the climate scenario.

While most energy in Africa is still dependent on coal, crude oil, and gas (more than 50% of total energy supply), hydropower is a key source of power in the region accounting for just under 20% of total generation in 2021. In East and Southern African countries hydropower is a larger source of electricity generation. Estimates by Arndt et al. (2019) which uses an uncertainty approach to assess the impact of climate change on runoff in the 5 major basins of the Zambeze River Valley indicate a decrease in runoff across most basins (mode) with potentially large declines in runoff (up to 50%) possible in the Kafue and

Upper Zambezi basins. Increases in runoff are also possible in some basins. Changes in runoff have implications for water allocations for irrigation and hydropower. In the case of hydropower, the results show likely losses in the case of Zambia and to a milder extent in Mozambique as well. The IEA highlight Morocco, Zambia, Zimbabwe, the Democratic Republic of Congo, and Mozambique as key countries vulnerable to decreasing hydropower generation due to climate change. Increased frequency of extreme events such as drought also increases hydropower vulnerability in Africa. This has been illustrated in Malawi, Tanzania, Zambia, and Zimbabwe during the 2015/16 El Niño. Expansions in hydropower capacity to meet rising demand in the region would result in long term climate change vulnerability. Further research is needed to better understand the impacts of climate change on the water-energy-food nexus in the region as a whole (Trisos et al. 2022).

Africa is a key tourist destination in the world because of its many biodiverse regions which inhibit several species of plant and animal life not found anywhere else in the world. As a result, tourism is an important economic activity across most of Africa, contributing around 8.5% to total GDP and employing nearly 9 million workers (Trisos et al. 2022). Climate change through droughts, heat stress and flooding has negatively impacted the sector as it has disrupted wildlife migrations, decreased viewing opportunities, and damaged infrastructure. The IPCC projects further negative impacts on nature-based tourism in the region due to climate change as temperatures continue to increase, precipitation decreases and becomes more uncertain, and the frequency and severity of extreme events rise. Sea level increases are expected to reduce beach tourism in the future.

Climate change, particularly extreme events, also affects broader economic activity through the impacts on infrastructure and labour productivity for example. Infrastructure across many countries in Africa remains insufficient and inadequate, constraining economic growth and development in the region. Estimates indicate that poor infrastructure in the region adds between 30-40% to the costs of goods traded between African countries. Climate change is expected to place pressure on existing infrastructure, increasing the financial burden faced by many countries. The IPCC (Trisos et al. 2022) estimates that without adaptation, sea level rise would result in infrastructure damages of between USD 65- 87 billion by 2050 (includes only 12 major coastal African cities), while costs of just maintaining existing road infrastructure would reach USD 183.6 by 2100.

Labour productivity is another key broad-based sector input that will be negatively affected under climate change. Climate change is expected to lead to higher temperatures in the region, increased extreme heat days as well as increased extreme events such as flooding. These changes will negatively affect health and hence productivity in the region. The impacts are expected to be larger because of outdoor work, buildings that can manage heat, less use of air conditioning systems. The IPCC estimates that increased climate-induced heat stress will decrease working hours and capacity in the region with the largest declines being experienced in sub-Saharan Africa and in outdoor occupations. Under a global warming scenario of 3%, labour capacity in agriculture is expected to decrease by between 30-50% in sub-Saharan Africa. In West Africa, labour productivity under the same global climate is expected to cost up to 8% of GDP. Manufacturing productivity across Africa is projected to decline under RCP8.5 by 0–15% by 2080–2099, with the largest effects in the DRC, Ethiopia, Somalia, Mozambique, and Malawi (Trisos et al. 2022).

Actions arising from climate change include the need to reduce emissions and build resilience through climate adaptation. While many African countries are not large producers of emissions, emissions are expected to increase given current energy structures (primarily coal based), growing populations and economic development. Africa however has significant renewable energy endowments which provide a clean energy alternative to many countries in the region. Existing low levels of sunk costs within the energy sector also reduce the risk or cost of stranded assets in many countries (Arndt et al. 2020), while the need for development and expansion in energy access provides an opportunity for considering decentralised power systems. Energy transitions in Africa also creates the potential for regional approaches which may assist in meeting energy needs while reducing emissions.

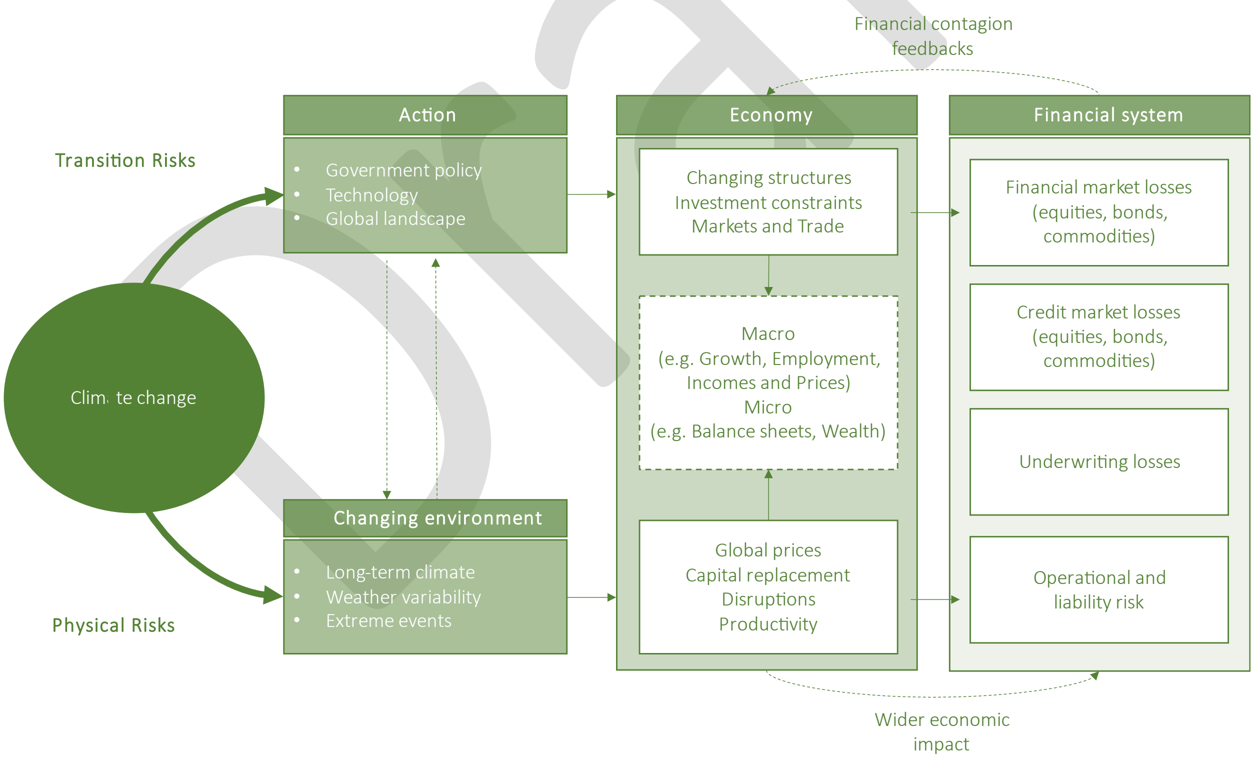
Global pressures and the need to reduce emissions to limit the physical impacts from climate change has resulted in almost all countries in Africa having committed to reducing their emissions via their Nationally Determined Contributions. While emissions in many countries are not large, structural shifts will still be needed to move toward low carbon economic development. Transitioning to low carbon economies and meeting Nationally Determined Contributions requires significant investments which cannot be fully financed by local governments. Significant risks exist with regards to being able to sufficiently attract such funding with the consequences of not be able to do so potentially including loss in market share as preferences shift away from carbon intensive goods and services. Transition risks are higher in countries that depend on fossil fuel extractive industries as primary energy inputs and sources of foreign revenue. Examples of such countries include South Africa (dependence on coal), Nigeria (crude oil), and Algeria (natural gas). Local and global energy transitions however do provide opportunities for new sector development for goods and services needed in the transition.

Although mentioned briefly throughout the risk discussion above, it is important to note that the risks from climate change in Africa are both local as well as global. Global risks include commodity price volatility, trade and supply shocks, and policy changes in response to climate shocks and mitigation ambition. Further research is needed to unpack the local and global risks of climate change in Africa and assess the impacts of these risks on macroeconomic growth, fiscal stability, and monetary policy. Macroeconomic assessments of transition and physical climate impacts in Africa are limited and further work is urgently needed to unpack these specifically at the national level given that climate risks may be unique to country characteristics.

Implications for central banking

Climate change directly affects central banking mandates through the risks imposed to financial and price stability in the economy as well as through the management of capital flows needed for climate transitions and adaptation. This is illustrated in Figure 1 which describes the transmission pathways in which transition and physical risks affect the macro economy and the financial system via relative price adjustments, changes in balance sheets and impacts on broader economic activity, and how financial system impacts can have feedback effects on the economy. As illustrated, transition risks impact the structure of economies as shifts in technologies require moving away from traditional production methods toward cleaner and more sustainable options. Such shifts have implications for upstream sectors. A key example here is changes in energy technologies from fossil fuel based toward renewable based which will negatively affect the demand for and production of fossil fuel extraction activities. Fossil fuels extraction is a key source of activity and revenue in many African countries. Decreasing domestic demand would therefore affect economic growth and result in job and income losses. Demand will also be affected by changes in external demand as the rest of the world moves toward low carbon growth and preferences shift toward greener goods and services. Shifts in technologies will also impact asset valuations and could potentially lead to the stranding of assets which have implications for company balance sheets. Impacts on company incomes and balance sheets weaken financial positions and raise the risk of defaulting on credit obligations. Similarly job and income losses also raise the risk of individual credit defaults. The transition to a low carbon economy can also impact prices through policy changes that introduce carbon prices, and increased investments needed for cleaner and more efficient technologies. Physical climate impacts can lead to short- and long-term risks to financial and price stability. In the long-term changes in climate change affects productivity and hence economic output and prices. A key example is the impact of climate change on food production and prices with hotter and drier climatic conditions in much of Africa leading to lower crop yields and increased dependence on food imports. In the short term, extreme weather events may lead to large price volatility because of capital destruction and economic disruptions experienced. Climate risks to financial and price stability extend beyond national boundaries as countries are exposed to global climate impacts through trade.

Figure 1 Impacts of transition and physical risk



While the section above describes the generalised risks of climate change to financial and price stability and central banking, the risks for Africa (and other developing countries) may be more unique and severe. This is due to the higher exposure of many African countries to climate shocks (discussed above), but also because of shallower financial markets, less developed regulatory frameworks, and more constrained fiscal positions with already higher borrowing costs than in developed countries (Adam et al. 2023, Arndt et al. 2020). The higher risk of climate shocks in the region means that the physical impacts of climate change will lead to larger and more compounding effects on the economy. These shocks will place additional pressures on already constrained fiscal resources further limiting the ability for government financing of transition and adaptation investments. Constrained government resources, along with shallow financial markets mean that a large share of financing for climate transitions and adaptations will need to come from abroad. Adam et al. (2023) reports that government financing can only account for 10% of financing needed for transition and adaptation financing. Central banks have an important role to play in both efficiently managing the flows of these funds as well as attracting them by ensuring a stable macro economy and that risks from climate are incorporated and correctly priced. Correctly pricing risks will also ensure that resources are effectively allocated within countries and that markets, such as insurance, are included relevant information. Understanding the risks and opportunities induced by climate change are important for central banks to create enabling environments for investment whilst maintaining economic and financial stability.

Frameworks for assessing climate risks

The potential risks emanating from physical and transition climate risks to the financial sector and monetary policy has aroused the need for central banks to better understand the impacts of climate change on the economy and financial sector. This is particularly important for countries in Africa where not only are climate impacts likely to be larger but financial markets and institutions are less sophisticated, fiscal, and monetary space is more constrained, inflation is higher, and borrowing costs are larger. The large and unprecedented nature of climate change shocks, high level of uncertainty, and long-term horizon of climate impacts makes many traditional central banking assessment tools by themselves less useful for climate foresight analysis and stress testing. The development of appropriate risk assessment and management tools that link climate, real structural economic, financial sector and risk dynamics is therefore needed. Specifically, such assessment tools must be capable of (i) identifying country specific climate scenarios, (ii) assess the economic impacts of these scenarios, and (iii) translate these impacts to the financial sector to measure vulnerability and exposure (Anvari et al., 2022).

One approach to improving central banking assessment frameworks is to link traditional macroeconomic and financial stability models with frameworks designed to assess the physical and transition impacts of climate change. Country specific integrated assessment models that include computable general equilibrium models are useful frameworks for assessing the impacts of climate change as they unpack the impact of changes in temperature, precipitation and weather on key channels affecting the economy by linking impacts through biophysical models such as crop yield, water supply and demand, energy, and infrastructure models. Such frameworks enable more accurate assessments of climate change impacts and identification of risks as they include country specific characteristics and account for heterogenous within country impacts. Sector-specific biophysical models generally evaluate impacts at a granular level identifying key vulnerabilities as well as potential adaptation opportunities. Computable general equilibrium (CGE) models are well suited for assessing the economic impacts of climate change as they are structural models based on microeconomic theory and capture the functioning of the real market economy in which the interactions of producers, households, government, and the rest of the world are mediated via prices and markets. CGE models include detailed supply side information necessary for analysing climate change which is characterised by large supply side shocks. CGE models have been widely used to look at both the transition and physical risks of climate change (An et al., 2023) and for many African countries, models of key climate impact channels such as agriculture, infrastructure and water already exist (Arndt et al., 2020). Linking information from such models with more traditional macroeconomic and financial models will ensure that the country specific and appropriate costs and benefits are included in analysis and provides detailed information for the financial sector to use in identifying and costing their own risks to climate change.

South African Case Study

Framework for assessing climate risks in South Africa

To assess the fiscal and monetary policy implications of climate risk in South Africa, we employ a multi model framework that links macroeconomic climate impact and transition analysis with traditional macroeconomic modelling tools used by central banks. The modelling framework employed is illustrated in Figure 2 and uses the Network for Greening the Financial System (NGFS 2023) scenarios as a guide to the state of the global economy. Specifically, the NGFS Current Policy, Delayed Transition and Net Zero 2050 scenarios are selected. Within each of the global scenarios specific scenarios are developed for South Africa to assess the economic impacts of physical and transition climate induced changes. Figure 3 presents the change in temperatures experienced and the annual level of emissions produced in each scenario for South Africa. It is important to note that in the case of physical climate impacts, we only consider one possible climate future within each global scenario. This climate future is taken from the tail end of the distribution and represents a bad climate outcome.

Figure 2 Modelling framework applied to South Africa.

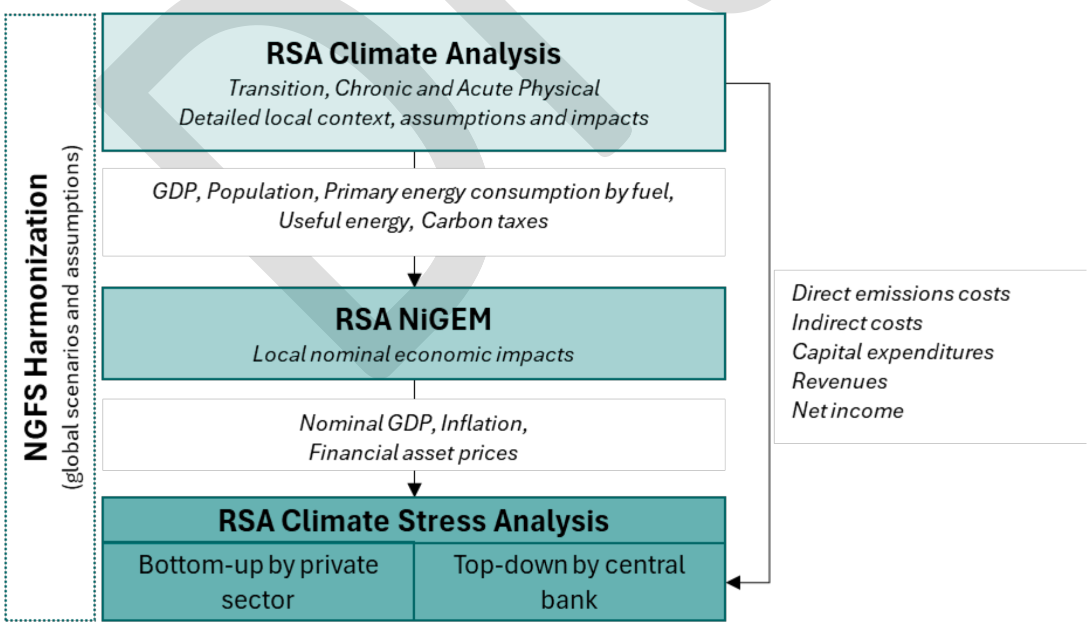
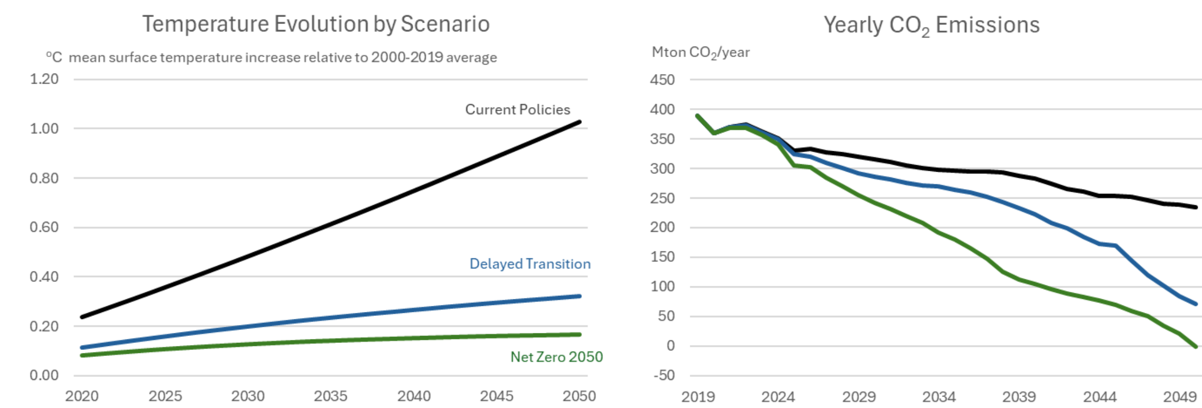


Figure 3 Temperature change (left) and annual emissions (right) for South Africa by scenario



The physical impacts of climate change are modelled using the SACReD (Systematic Analysis for Climate Resilient Development) modelling framework. SACReD is a multi-model framework that links global and national changes in climatic conditions to country specific biophysical models that captures the key channels through which climate change affect the economy. The outputs from these biophysical models are then linked to an economy-wide model for South Africa to quantify the impacts of physical climate changes (see DEA 2016 for a previous application of SACReD to South Africa).

The economic transition impacts associated with climate mitigation are modelled in a linked energy-economic model for the country, called SATIM-GE. SATIM-GE is a hard linked model that combines an engineering bottom-up energy systems optimisation model with an economy-wide model (see Marquard et al., 2021). The use of such an approach for transition risk analysis ensures that country specific technical energy considerations are accounted for and that the economic impacts of changes in the energy system are consistently estimated.

The outcomes from the SACReD and SATIM-GE models provide outcomes of the macroeconomic impacts of climate change generally used by central banks as well as detailed impacts on sectors and households. Both the SACReD and SATIM-GE models however provide real side structural economic impact outcomes. Key outcomes from the model are therefore used to inform a South African NiGEM model to estimate financial side indicators needed for central bank analysis. Detailed sector and household information from SACReD and SATIM-GE are used to provide more information on the specific changes in the economy that can assist financial sector institutions in identifying and quantifying their risks to climate change. The outputs from these models thus assist in conducting both top-down and bottom-up stress testing exercises for South Africa.

This framework provides a useful tool for climate change analysis as it models impacts at the national and sub-national level. This ensures that the appropriate and differentiated shocks applicable specifically to South Africa are included rather than aggregated shocks when using global integrated assessment frameworks. The linking of expert models enables the inclusion of country specific characteristics as well as technical detail for considering the different implications of physical and transition climate impacts. Linking models ensures that the strengths of individual models are retained while at the same time enabling the assessment on the economy. In the case of the energy linked economic model, the hard link between the two models reduces shortcomings often presented in mitigation analysis such as lack of engineering detail and feedback effects from behavioural changes.

Climate risks in South Africa

Climate change negatively affects real GDP. Cumulatively the combined impact of transition and physical shocks to the economy reduce GDP by 8.8% and 11.1% in the Delayed Transition and Net Zero 2050 scenarios. The larger cumulative decrease under Net Zero 2050 is due to the larger transition impact, while the physical climate impact between the two scenarios is similar. The similar physical climate impact is driven by the loss in capital associated with flooding which for the given climate future considered is worse for most of the modelled period under Net Zero 2050 than Delayed Transitions. The Delayed Transition scenario here does not include any impact on confidence as assumed by the NGFS.

The Current Policies scenario includes a least cost plan for energy with no forced emissions decline. This is considered the reference case for energy production in South Africa and as a result no transition cost is reported. The physical impact cost to GDP is 8.4% by 2050. This cost, however, excludes any changes in preferences for emissions intensive goods or services as well as carbon border tax adjustment measures (CBAM) which may be experienced. Merven et al. (forthcoming) estimates the loss in GDP associated with the EU CBAM to be 0.9% by 2050. This however assumes that a CBAM of 85 Euro is only imposed by the EU on the six products currently noted (i.e. cement, iron and steel, aluminium, fertiliser, electricity, and hydrogen) over the period 2026 to 2050. A CBAM with fuller trade partner and product coverage is estimated to reduce GDP by 9.3% by 2050.

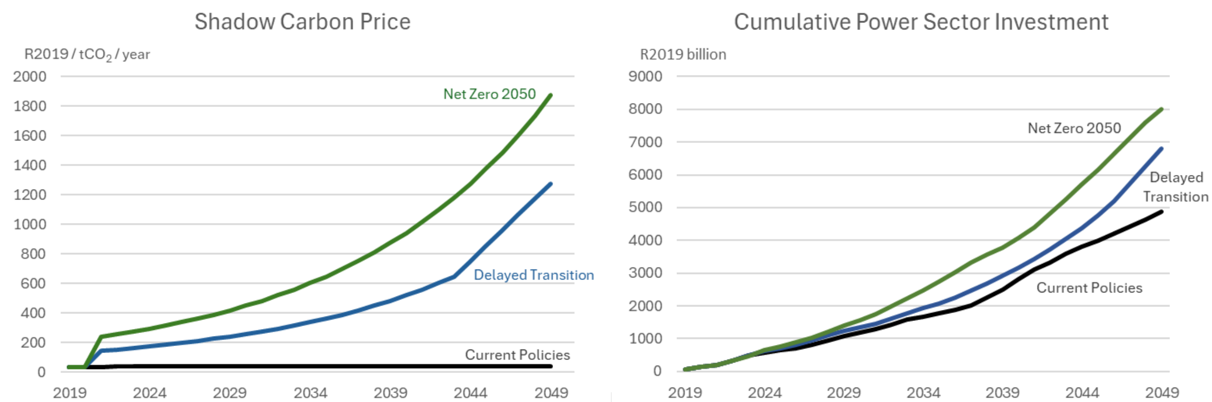
For the climate future selected, the results show that the physically induced climate impacts are larger than those emanating from the transition to a low carbon economy. The physical climate impact is largely driven by the loss in capital due to flooding which has broad economic impacts. The water availability and crop yield climate impact channels are smaller. Agriculture GDP decreases by between 7.0% and 7.9% under the climate scenarios analysed. The sector accounts for 2.8% of total GDP (StatsSA 2024).

Table 1 Physical and transition climate impact on real sector GDP level relative to no climate change, %

	Transition		Physical		
	Delayed Transition	Net Zero 2050	Current Policies	Delayed Transition	Net Zero 2050
Agriculture, fishing and forestry	-2.0	-3.3	-7.9	-7.2	-7.0
Mining	-10.1	-21.2	-8.1	-6.0	-6.3
Manufacturing	-2.4	-5.7	-7.7	-5.9	-6.2
Electricity, gas and water	6.5	19.7	-7.9	-6.0	-6.2
Construction	-5.9	-7.8	-8.0	-6.1	-6.4
Wholesale, trade and accommodation	-2.8	-4.9	-7.8	-6.0	-6.2
Transport and communication	-0.6	0.3	-7.7	-5.8	-6.1
Financial and business services	-2.3	-4.5	-8.2	-6.2	-6.5
Community and other services	-1.8	-3.3	-6.0	-4.5	-4.8
Total GDP	-2.5	-4.5	-8.4	-6.4	-6.6

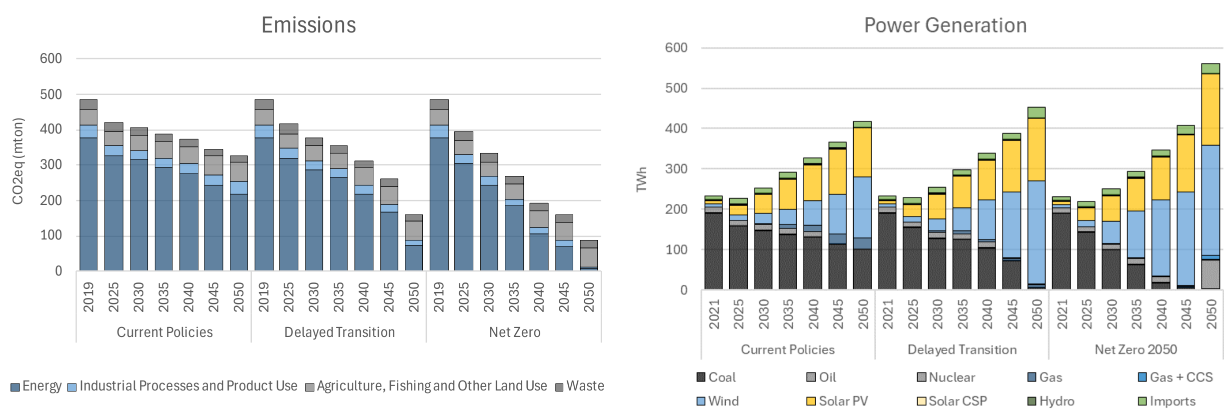
Transitioning to a lower carbon intensive economy requires significant increases in mitigation effort (policies and measures). This is illustrated by the shadow carbon price (Figure 4) which increases from R37/ton CO_2 in 2049 in Current Policy to R1 277 and R1 875 in Delayed Transitions and Net Zero 2050 respectively. The transition impact is driven by the need for additional investment to shift the energy system from coal and crude oil to renewable energy, crowding out investment in other sectors as the relative price of capital increases. In the scenarios modelled here, we assume that mitigation is locally funded. Figure 5 presents the cumulative level of investment needed in the power sector for each of the scenarios considered. Higher electricity prices also increase production costs, resulting in decreased domestic demand.

Figure 4 Shadow carbon price (left) and cumulative power sector investment (right)



Emissions declines in South Africa are driven by declines in the energy sector, specifically power generation (see Figure 5). The power system shifts from coal to renewable energy across scenarios, although in the Delayed Transition and Net Zero 2050 scenarios these shifts are larger and occur earlier. The shift to renewable energy enables mitigation in other sectors such as transport and industry with clean electricity providing an alternative fuel to coal and crude oil. This increases demand for electricity as the economy becomes more electrified.

Figure 5 Emissions by IPCC sector (left) and Power generation by technology (right)



Climate impacts affect the structure of the economy. As illustrated in Table 1, the composition of sector GDP changes because of climate change with sectors affected differently by physical and transition climate changes. By 2050, physical climate most negatively affects the agriculture and finance sectors, reducing their shares in total GDP. Community and other services are also least affected by physical climate impacts. Transition impacts most negatively affect the mining and construction sectors with the sectors least affected or positively affected including electricity, transport, and community and other services. The mining sector is negatively affected by the decline in demand for coal, but also other mining sub-sectors which are negatively affected by the strengthening of the exchange rate as the import bill decreases due to declines in crude oil and petroleum product imports (as transport shifts toward using more electricity), lower gas imports, as well as lower overall demand. Demand for petroleum fuels decreases traditional transport technologies are replaced by electric, hydrogen, and hybrid options. Refinery production declines as domestic production becomes more expensive than imports - by 2034, domestic production decreases by half and by 2049 all domestic production ceases. Within manufacturing, the sectors most affected are non-energy sector related machinery, vehicles, and metal products. The development of new sectors, namely hydrogen and linked production sectors such as fuel cells and electrolysers provide some support to manufacturing growth as does localisation although the latter also increases demand for resources which negatively affects non-energy related production. This is the case in construction where energy related construction activity increases while non-energy related construction decreases. Electricity production increases over the period as the economy becomes more electrified.

Table 2 Physical and transition climate impact on employment relative to no climate change, '000s

	Transition		Physical		
	Delayed Transition	Net Zero 2050	Current Policies	Delayed Transition	Net Zero 2050
Agriculture, fishing and forestry	6	0	117	2	21
Mining	-130	-260	-48	-14	-22
Manufacturing	-95	-242	-81	-50	-55
Electricity, gas and water	39	51	-9	-4	-6
Construction	-290	-347	-264	-190	-196
Wholesale, trade and accommodation	-111	-255	-171	-125	-128
Transport and communication	41	46	-36	-19	-22
Financial and business services	-26	-181	-81	-55	-58
Community and other services	-148	-354	-1296	-979	-1012
Total	-714	-1541	-1869	-1434	-1477

Declines in activity result in lower employment, household incomes and expenditure. Across the scenarios between 1.5 and 2 million fewer job opportunities are created due to physical climate impacts, while 700,000 and 1.5 million fewer jobs are created in Delayed Transition and Net Zero 2050 due to the impact of the transition. Job losses are concentrated in the Community and other services, Construction, and Wholesale, trade, and accommodation sectors. In terms of percent change in employment, the mining sector employs between 2% and 25% less workers relative to no climate change. The sector, along with Community and other services, Construction, and Wholesale, trade, and accommodation, and manufacturing become smaller employers of labour relative to no climate change. Additional employment opportunities are however also created, specifically in the Agriculture, Electricity, and Transport and Communication sectors. In agriculture the employment opportunities are primarily driven by the physical climate impact as lower production and rising global prices increases profitability in the sector and increased labour use compensates for climate induced yield productivity losses. Rising capital costs from increased infrastructure depreciation also results in a shift toward more labour use in the sector. Increased employment in the Electricity sector is driven by the expansion of the sector as production increases. Lower employment negatively affects household incomes and consumption. Higher income households, who primarily receive their incomes from labour, capital, and enterprise income, experience larger declines in income than lower income households who receive the bulk of their incomes from transfers and lower skilled employment, the latter sees smaller decreases in employment. Consumption declines are largest for services such as Financial and business services, and Wholesale, trade, and accommodation. Agriculture and food consumption is also negatively affected.

Implications for macro-financial economic indicators used in stress-testing

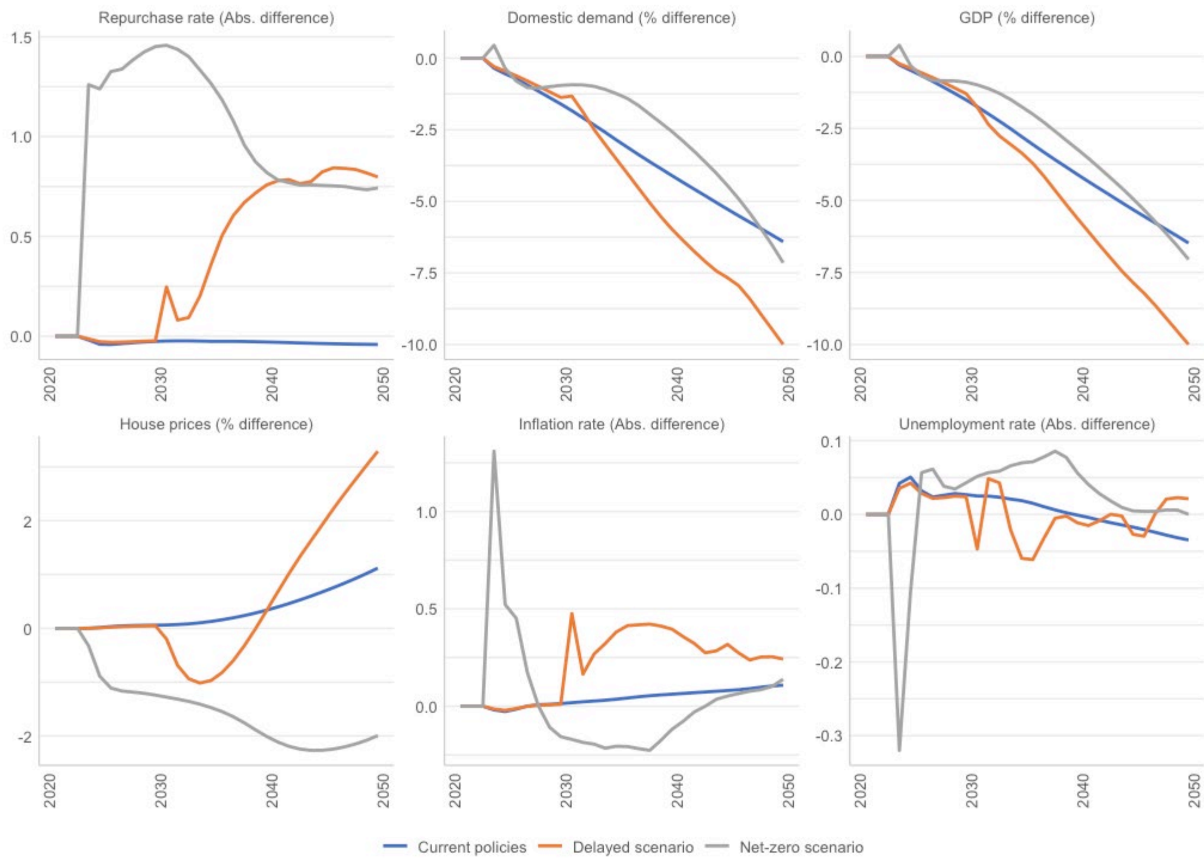
The results discussed above present the outputs from the structural economic modelling for South Africa. These outputs are used in the NiGEM model to estimate the impact of climate change on key macro-financial economic indicators used in stress-testing (see Figure 6). In addition to the structural modelling outputs and assumptions, the NiGEM model also includes an investment premium in 2030 and 2031 in the Delayed Transition scenario to account for the impact of policy uncertainty on investor confidence in the scenario. In all scenarios the impact of carbon revenue recycling based on emissions and the shadow carbon tax outputs from above are also included. It is important to note that the impact of the later in the NiGEM analysis is likely to be overestimated as the shadow carbon tax is indicative of government policy intensity and changes in technology and consumer preferences needed to reduce emissions and not only the policy implementation of a carbon tax. The implications of these differences result in the Delayed Transition scenario having the largest negative impact on real GDP by 2050 and the Net Zero 2050 having the smallest average impact over the modelled period. NiGEM assumes rational expectations and follows a 2-pillar strategy in which both inflation and GDP is targeted (NGFS 2023b).

Climate change raises the risk of price instability. Inflation is higher across all three climate scenarios, although the timing and duration of the rise in price growth differs. Inflationary pressures are driven by the transition, specifically the rise in the carbon tax rate. This can be clearly seen under the Net Zero 2050 scenario where the marked increase in the carbon tax rate results in a large increase in inflation. The physical impacts of climate change are found to have a small deflationary impact due to their large negative impact on domestic demand and GDP. Again, it is important to note that in Current Policies we are only measuring the physical impact of climate change as no climate forced transition is being implemented. The risk of price instability is higher under the Delayed Transition scenario as indicated by the higher long term inflation rate relative to Net Zero 2050 and Current Policies.

Higher inflation leads to higher interest rates, raising the cost of borrowing and negatively affecting domestic demand and GDP. The repurchase rate remains higher under climate change in both the Net Zero 2050 and Delayed Transition scenarios, although the steep initial increase under Net Zero 2050 is in response to the larger inflation increase. Interest rates remain elevated relative to Current Policies under the medium to long term due to continued inflationary pressures. The demand and GDP impact under Net Zero 2050 is less severe than Current Policies and Delayed Transition as the recycling of carbon tax revenues offsets some of the negative climate impact. Under the Net Zero 2050 scenario carbon tax revenues are assumed to be recycled via government investment and lower employment taxes. Under Delayed Transitions, carbon revenue recycling has a smaller offsetting impact as revenues are assumed to only be recycled via lower employment taxes given the disorderly nature of the scenario design.

Higher interest rates, lower incomes and losses in asset value increase the risk of credit defaults. While this paper does not assess the exposures to credit defaults in the financial and banking sector, the indicators below highlight the heightened potential for such an occurrence. Higher interest rates increase debt obligations, while lower domestic demand and economic activity reduce available incomes. Loss in asset valuations, as illustrated for example by the decline in household prices, further reduces net worth and the potential to meet debt obligations. This coupled with the narrowing interest margins banks could experience under higher interest rates raises risks for the banking sector. Higher interest rates also threaten the success of mitigation efforts as it raises the cost of borrowing funds needed for clean energy adoption, raising the cost of mitigation. The results from the local models discussed above provide an indication of the sectors at risk from climate change.

Figure 6 Summary of macro-financial economic indicators used in stress-testing



Discussion

Climate change is expected to have large and unprecedented impacts on economies and economic structures, particularly in developing countries the global south. These impacts create risks to the financial sector and the mandates of central banks through their impacts on economic activity, incomes, price stability and asset valuations. Understanding the vulnerability of the financial and banking system is necessary for central banks to deliver on price and macroeconomic stability.

The complexity of climate change, however, requires the use and development of new tools or frameworks that enable analysis to account for changes in global environments but that focus on local impacts and outputs needed by central bankers for assessments of the health of the financial system and monetary policy.

The assessment frameworks required need to be able to effectively model the impacts of climate change (both transition and physical risks), translate these impacts into indicators relevant for the financial sector and central banks, and be translatable as inputs into existing frameworks used by these institutions. Furthermore, necessary skills are needed to appropriately design and develop the climate scenarios considered such that they are relevant for the interests of central banks. This integration of different modelling elements and skills requires a multidisciplinary approach to unpack the risks climate change poses to central banks.

The case study for South Africa presents a potential framework for assessing climate change risks that could be replicated in other African countries relatively easily given the adaptability of the local framework and the existence of economy-wide models in many African developing countries. IFPRI models are for example available in about 20 African countries. The outputs from the South African analysis illustrate the level of detail that such modelling frameworks can provide. Such outputs can assist in company level analysis of climate change exposure and risk. Extending the analysis from single climate scenarios, as done in the South African case study, to multiple scenarios can improve in the assessment of climate change risks as the range of climate change uncertainty can be considered.

All models have limitations and space for further development and improvement. The limitations of current models for climate change and central bank analysis, including stress testing, are highlighted in Anvari et al. (2022). The modelling framework presented here for South Africa tries to address some of these limitations (e.g. missing financial dynamics via linking local structural models with the NiGEM model) but further work is required.

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