Climate Change and Financial Stability: Evidence from Southern Africa

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Abstract

This study investigates the dynamic impact of temperature variability on banking sector stability in Lesotho, Namibia, and Eswatini using a Local Projections framework. By modelling changes in non-performing loans, the analysis investigates how physical climate shocks transmit through banking sector stability, measured by non-performing loans (NPLs), over five years horizon. The results show that temperature increases are associated with higher NPLs, particularly in the short run and selected medium-term horizons, with evidence of persistence suggesting cumulative financial stress. Bank-specific characteristics significantly moderate these effects, indicating that stronger balance sheets enhance resilience, while significant country and year effects underscore the role of structural and macroeconomic conditions. The findings highlight the need to integrate climate change into prudential regulation and macroprudential surveillance, such as climate stress tests, to strengthen the banking sector's resilience against climate-related risks.

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1. Introduction

Financial regulators are increasingly concerned about the impact of climate change on banking sector stability, as it introduces significant risks capable of disrupting the financial system (Grippa & Demekas, 2021). Policymakers worldwide now recognize that climate change poses a material threat to financial stability, and the Southern African region is no exception (Anh-Tuan Le et al., 2023). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), climate risk is defined as the potential, under conditions of uncertainty, for adverse consequences affecting lives, livelihoods, health, ecosystems and species, as well as economic, social, and cultural assets and services, including infrastructure and environmental services.

Climate-related risks are commonly categorized into two main drivers, and these are physical risks and transition risks (Anh-Tuan Le et al., 2023; Financial Stability Board & Climate Transparency International, 2020). According to (Le et al., 2023), physical risks arise from changes in climate patterns, including chronic risks such as rising temperatures and sea levels, and acute risks such as storms, floods, droughts, and extreme rainfall. As such, these events can damage productive assets, disrupt economic activity, and impair borrowers' repayment capacity. Consequently, banks exposed to physical risks may experience financial losses stemming from increased credit risk, asset devaluations, and heightened uncertainty associated with more frequent and severe climate-related shocks.

Transition risks, by contrast, refer to potential financial losses arising from the adjustment toward a low-carbon and environmentally sustainable economy (Nie et al., 2023). These risks may be triggered by sudden or stringent climate policies, technological innovations, or shifts in consumer preferences. Such changes can negatively affect carbon-intensive sectors, thereby increasing credit risk for banks with concentrated exposures to these industries.

The banking sector plays a central position in the economy through its lending and investment decisions, which directly influence economic growth and financial stability (Zhou et al., 2023). The global financial crisis of 2008–2009 demonstrated how inadequate risk assessment and excessive exposure to high-risk assets can destabilize the entire financial system. In a similar vein, climate-related risks represent a growing source of systemic vulnerability, as banks are directly exposed to both physical and transition risks (Gramlich et al., 2023). Continued investment in carbon-intensive sectors without adequate consideration of climate-related financial risks may lead to asset stranding, rising defaults, and increasing regulatory pressure. Conversely, integrating climate risk into banks' risk management frameworks and promoting sustainable finance can enhance financial resilience while supporting the transition to a low-carbon economy (Chabot, Bertrand & Courquin, 2024).

Given these vulnerabilities, it has become imperative for supervisors and central banks to incorporate climate risks into prudential and regulatory frameworks. Recognizing the systemic nature of climate-related financial risks, central banks, policymakers, and financial regulators are increasingly collaborating to embed climate considerations within supervisory mandates. In this regard, the Basel Committee on Banking Supervision (BCBS) and the Network for Greening the Financial System (NGFS) have issued guidance on the identification, assessment, and management of climate-related financial risks. These initiatives aim to strengthen financial stability by enhancing risk assessment practices and encouraging proactive mitigation of the long-term economic consequences of climate change (Anh-Tuan Le, 2023).

Recent recommendations from the Financial Stability Board (FSB) further emphasize the need for financial institutions to assess climate risk exposures and conduct climate stress tests (Baudino & Svoronos, 2021). However, existing risk assessment frameworks remain necessary but inefficient to fully capture climate-related risks. The distinctive features of climate risks, such as uncertainty, non-linear impacts, feedback effects, and endogeneity, pose significant challenges for traditional macroeconomic and financial models (Mauderer, 2023; Sacchi & Volland, 2022). Moreover, the long-time horizons and complex interactions between climate dynamics, economic activity, and policy responses limit the effectiveness of conventional modelling approaches (CEPR, 2023; Institute for Sustainable Finance, 2022). Addressing these shortcomings requires the development of new analytical tools, including forward-looking models and scenario-based stress testing frameworks capable of capturing the multifaceted nature of climate-related financial risks (IMF, 2020).

While much of the existing literature focuses on advanced economies, climate change poses equally, if not more severe risks for vulnerable regions such as Southern Africa. The region is already experiencing rising temperatures, changing precipitation patterns, and an increasing frequency of extreme weather events, particularly droughts (Tomalka et al., 2023). These climatic shifts threaten agricultural production, water availability, infrastructure, and overall economic activity, with direct and indirect implications for financial stability. Southern Africa's climate is shaped by its geographic location and elevation, resulting in substantial cross-country temperature variation, typically peaking during the summer months. Precipitation patterns are influenced by global atmospheric circulation, interactions between the warm Indian Ocean and the cold Atlantic Ocean, and, critically, the El Niño–Southern Oscillation (ENSO). El Niño episodes are generally associated with hotter and drier conditions, whereas La Niña events tend to bring above-average rainfall. ENSO dynamics also contribute to extreme weather events, including cyclones, floods, and prolonged droughts (Tomalka et al., 2023).

Despite the growing literature on climate-related risks, empirical evidence for Southern African economies remains limited. Existing studies predominantly focus on advanced economies or large emerging markets, leaving smaller, agriculture-dependent countries such as Lesotho, Namibia, and Eswatini underexplored, despite their pronounced climate vulnerability.

Against this backdrop, understanding the interaction between climate dynamics and banking sector stability is essential for building resilience in Southern Africa. The region's heightened exposure to climate risks raises important questions about how climate shocks are transmitted through the banking sector and how policymakers can design effective frameworks to safeguard financial and macroeconomic stability. Accordingly, this study investigates the effect of climate change risk, measured by temperature changes as a proxy for physical risk, on banking sector stability, measured by the changes in the non-performing loans (NPL) ratio, in three Southern African countries: Lesotho, Eswatini, and Namibia. The study aims to shed light on the transmission mechanisms through which climate shocks affect banking stability, including channels operating through macroeconomic conditions.

This paper makes three key contributions. First, it applies a Local Projections (LP) framework to examine the dynamic effects of temperature shocks on banking sector stability, allowing for flexible impulse response estimation that is robust to model misspecification. Second, the study underscores the policy relevance of climate-related financial risks for small, agriculture-dependent financial systems, offering insights for banking supervision, climate stress testing, and risk management in climate-vulnerable economies.

The empirical findings indicate that temperature shocks are associated with an increase in credit risk (NPLs) in the short run, with effects persisting over subsequent periods, although evidence of partial stabilisation emerges at longer horizons. These results highlight the importance of incorporating climate change risks into macro prudential surveillance and financial stability assessments, such as climate stress tests.

The remainder of the paper is structured as follows: Section 2 provides an overview of climate-related risks in Southern Africa, Section 3 reviews the relevant literature, and Section 4 describes the data and methodology. Section 5 presents and discusses the empirical results. Section 6 concludes with policy implications, and Section 7 outlines the study's limitations and avenues for future research.

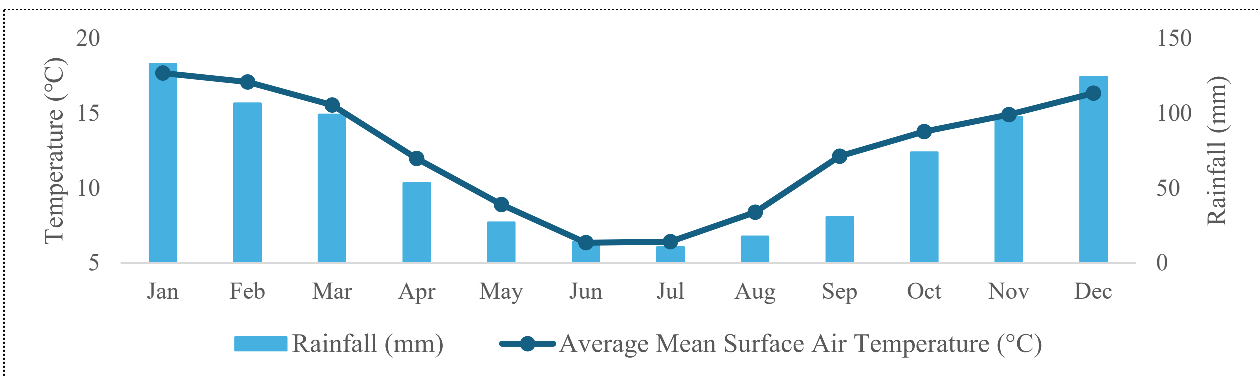
2 Overview of the climate-related risks in Southern African countries

2.1 Temperature Variations and Rainfall Trends in Lesotho, Namibia, and Eswatini

Southern African countries experience significant climate variability characterized by fluctuations in temperature and rainfall patterns. These climatic variations influence agricultural production, water availability, and household income stability, which may have important implications for financial sector resilience in climate-sensitive economies.

Lesotho exhibits notable temperature variability due to its high altitude and geographic location. Rainfall is highly seasonal and erratic, with precipitation largely concentrated during the summer months, while winters remain relatively dry. As illustrated in Figure 1, both temperature and rainfall display strong seasonal patterns over the period 1991–2021. This pronounced seasonality implies that agricultural output and household income remain highly sensitive to climate fluctuations, which may increase credit risk in rainfall-dependent sectors.

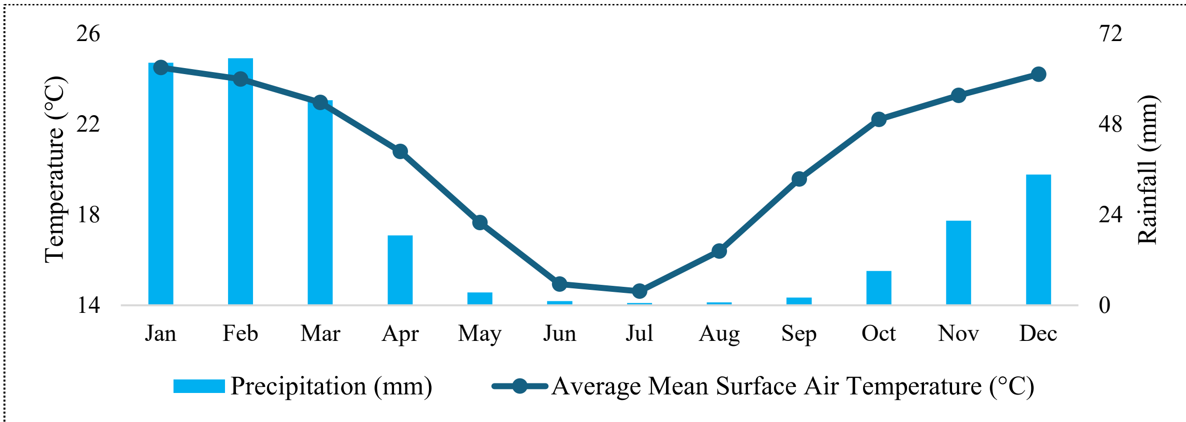
Figure 1: Average Monthly Temperature and Rainfall in Lesotho (1991-2021)



Source: Authors' own compilation based on data from the World Bank Climate Data (2021)

Namibia is characterized by relatively high temperatures and low, highly variable rainfall, with annual precipitation averaging approximately 278 millimeters. Rainfall is concentrated within a short seasonal window, as shown in Figure 2, with most precipitation occurring in the first quarter of the year. The concentration of rainfall within limited months increases vulnerability to drought conditions and water scarcity, which can disrupt economic activity and heighten credit risk exposure.

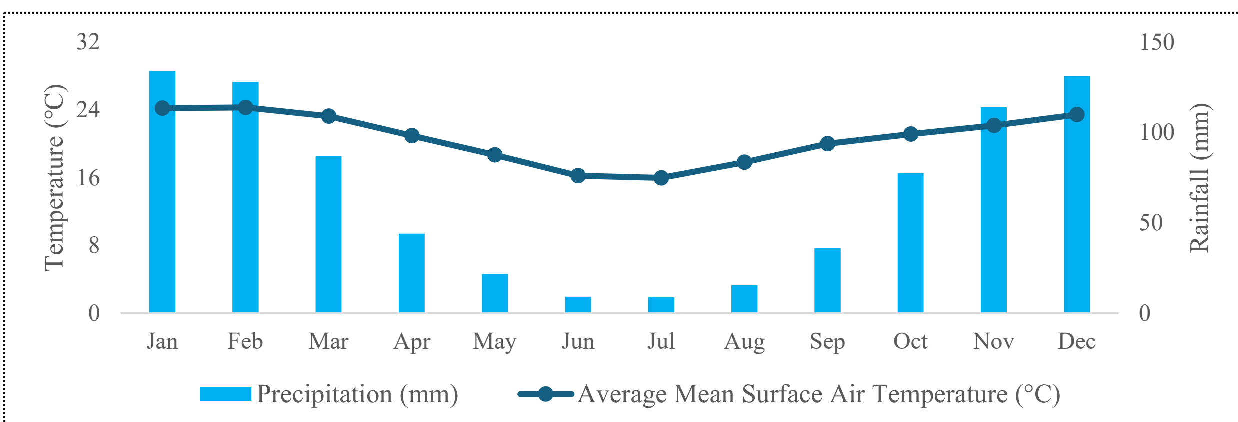
Figure 2: Average Monthly Temperature and Rainfall in Namibia (1991-2020)



Source: Authors' own compilation based on data from the World Bank Climate Data (2021)

Eswatini experiences a subtropical climate with warm, wet summers and cooler, dry winters. Rainfall is highly seasonal, with significant variability across months, as illustrated in Figure 3. The country has also experienced increasing temperature trends and shifts in rainfall patterns, including delayed onset of rains and more frequent dry spells. These developments contribute to agricultural instability and income volatility, with potential implications for borrower repayment capacity and financial stability.

Figure 3:Average Monthly Temperature and Rainfall in Eswatini (1991-2020)



Source: Authors' own compilation based on data from the World Bank Climate Data (2021)

2.2 Projected Average Temperatures by the World Bank Group (2021)

Climate projections suggest that temperature increases already observed across Southern Africa are likely to intensify in the coming decades. Climate modelling evidence indicates that Lesotho, Namibia, and Eswatini are projected to experience sustained warming under alternative emission scenarios, with particularly pronounced increases expected under high-emission pathways (World Bank Group, 2021a). These projections are consistent with global climate modelling studies, which highlight Southern Africa as one of the regions most vulnerable to rising temperature variability and extreme climate events.

2.3 Evolution of Climate Hazards and Their Relationship with Temperature Trends in Southern Africa

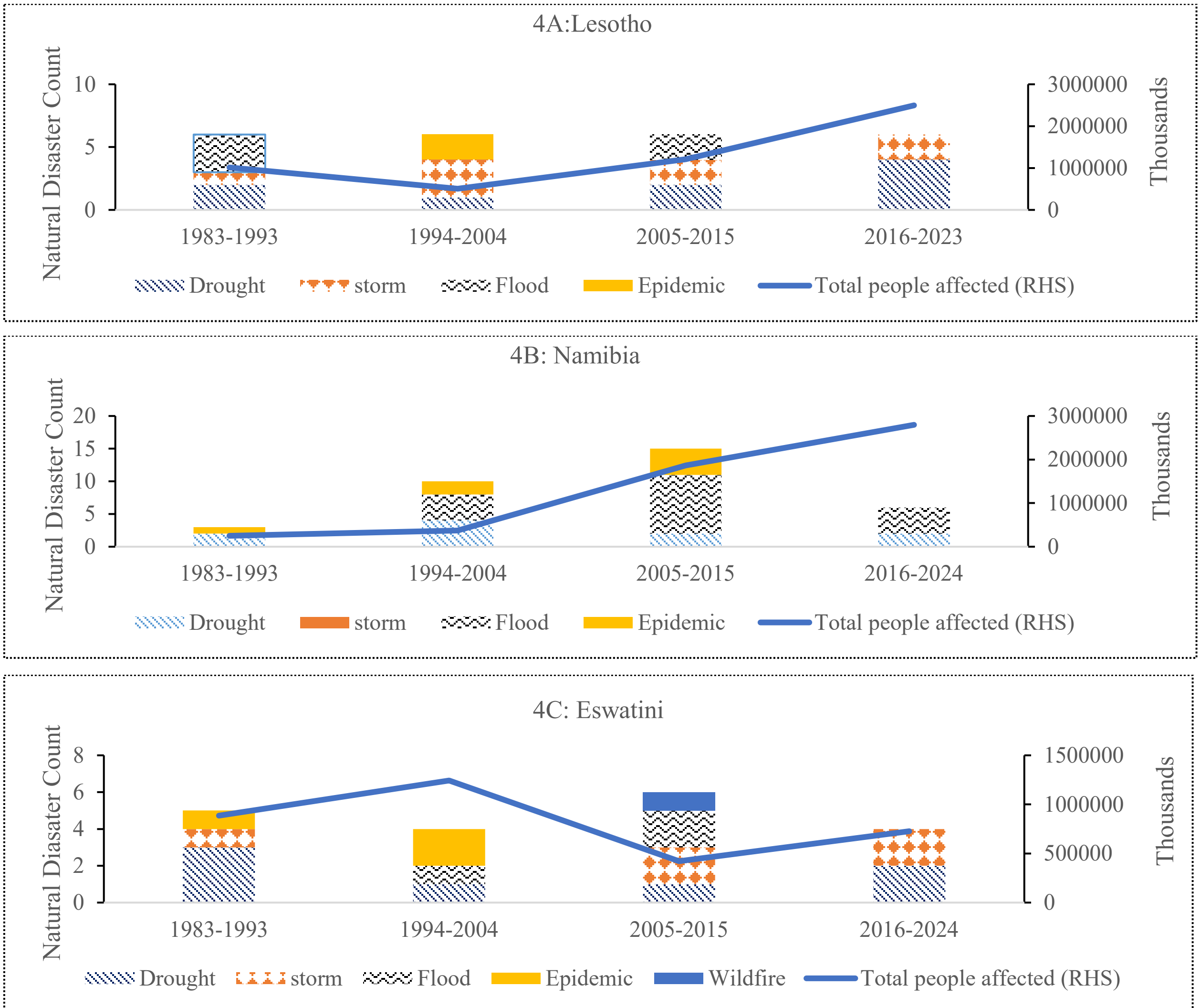
Southern African economies remain highly exposed to climate-related hazards, including droughts, floods, storms, and disease outbreaks. The frequency and severity of these hazards have evolved considerably over time, reflecting increasing climatic variability and environmental stress across the region. To better understand these developments, this section examines the temporal evolution of disaster occurrence and explores the interaction between temperature variability and climate hazard frequency in Lesotho, Namibia, and Eswatini.

Rising temperatures are expected to increase the frequency of heat waves, alter precipitation patterns, and intensify evapotranspiration processes. These changes are likely to amplify climate hazards such as droughts and floods, with direct implications for agricultural productivity, water availability, and ecosystem stability. Given the reliance of these economies on climate-sensitive sectors, such developments may adversely affect household income and economic performance.

While the magnitude of warming varies across countries, the overall regional pattern points to increasing climate vulnerability. Higher temperatures are expected to exacerbate water scarcity, reduce agricultural output, and increase exposure to heat stress across the region (World Bank Group, 2021a). These dynamics have important implications for financial stability, as they may weaken borrower repayment capacity and increase credit risk within the banking sector.

These projections underscore the importance of understanding how temperature shocks translate into macro-financial risks. In this context, financial regulators have increasingly emphasised the need to incorporate forward-looking climate risk assessments into macroprudential frameworks (NGFS, 2020; Baudino and Svoronos, 2021).

Figure 4: Natural Disaster Frequency and Severity in Lesotho, Namibia, and Eswatini



Source: Authors' own compilation based on data from EM-DAT: The International Disaster Database, CRED.

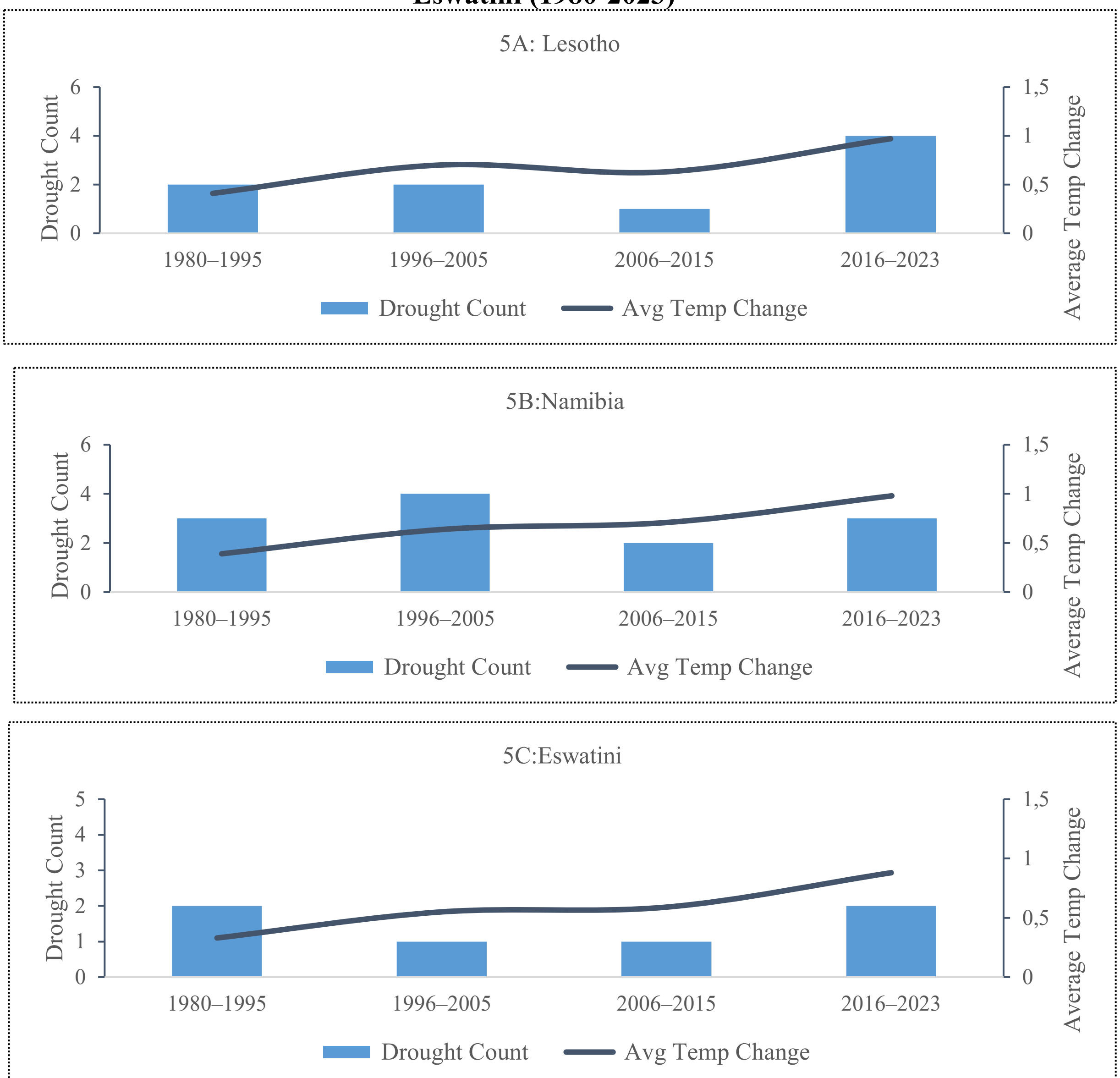
Figure 4 presents the evolution of major climate-related hazards across Lesotho, Namibia, and Eswatini over time. The figure indicates that while climate hazards have been present throughout the sample period, their frequency and severity have increased in recent decades.

Across all three countries, drought emerges as the most recurrent and economically significant hazard. In Lesotho, drought frequency increased notably from the mid-2000s, accompanied by a rise in the number of affected individuals. Namibia exhibits a similar pattern, with persistent drought conditions reflecting its arid climate, while flood events occur intermittently. In Eswatini, both droughts and floods have occurred more frequently over time, driven in part by changes in rainfall patterns and seasonal variability.

Overall, the evidence suggests that climate hazards in Southern Africa have intensified, increasing environmental and socio-economic vulnerability. This intensification is closely linked to rising temperature variability, which contributes to higher evaporation rates, reduced soil moisture, and greater likelihood of extreme weather events.

To further examine this relationship, Figure 5 illustrates the association between temperature variability and drought frequency across the three countries over the period 1980–2023.

Figure 5: Temperature Variability and Drought Frequency in Lesotho, Namibia, and Eswatini (1980-2023)



Source: Authors' own calculations based on temperature anomaly data from the FAO Climate Data Portal and drought event data from the EM-DAT International Disaster Database (CRED).

Figure 5 shows that across all three countries, the most recent period (2016-2023) is associated with higher temperature anomalies and relatively elevated drought occurrence compared to earlier decades, suggesting increasing exposure to physical climate risks.

Although the patterns differ somewhat across countries, the figure indicates that periods characterised by higher temperature variability tend to coincide with greater drought exposure. This observation is broadly consistent with climate science literature, which identifies rising temperatures as a key factor influencing drought conditions through their effects on evapotranspiration, soil moisture, and agricultural productivity.

The increasing occurrence of climate hazards has important implications for economic performance and financial stability in Southern Africa. Drought episodes can reduce agricultural output, weaken rural incomes, and increase food insecurity, while also affecting sectors linked to agriculture through supply chain disruptions. These effects may reduce borrowers' repayment capacity, weaken collateral values, and elevate credit risk within banking systems. Given the reliance of Lesotho, Namibia, and Eswatini on climate-sensitive sectors, such developments represent a growing source of macro-financial vulnerability.

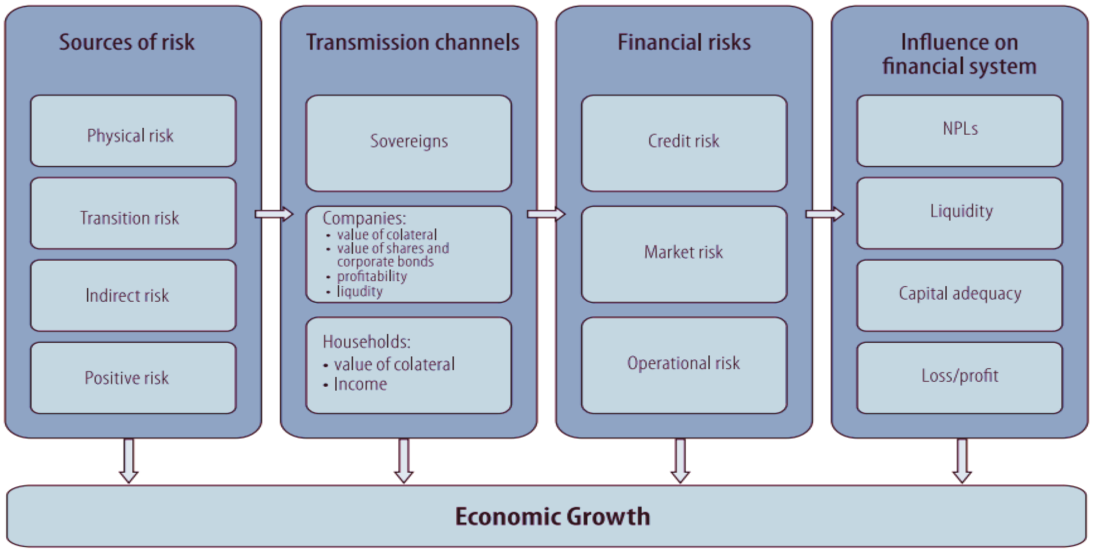
Overall, the stylised evidence presented in this section suggests that climate risks in Southern Africa have become more pronounced in recent decades, with temperature variability playing a potentially important role. These observations motivate the empirical analysis in subsequent sections, which formally examines the dynamic relationship between temperature shocks and banking sector stability.

3 Literature review

3.1 Theoretical literature

This section outlines the key transmission mechanisms through which climate-related risks may affect banking sector stability. Climate risks, both physical and transition, can propagate through financial systems via microeconomic and macroeconomic channels, ultimately affecting bank balance sheets and financial stability. Figure 6 provides a conceptual framework summarizing the transmission of climate-related risks to the financial system.

Figure 6: Climate change and financial risks implications



Source: Fabris, 2020

3.1.1 Microeconomic transmission channels

At the microeconomic level, climate-related risks affect financial institutions primarily through their impact on borrowers and counterparties. Physical risks such as droughts, floods, and rising temperatures can reduce agricultural output, damage productive assets, and weaken household and firm income. These effects may impair borrowers' repayment capacity, leading to an increase in credit risk and non-performing loans.

Transition risks may also affect firm profitability through regulatory changes, carbon pricing, and shifts in market preferences, particularly for carbon-intensive sectors. These developments can lead to asset devaluation and increased default risk. In addition, climate-related shocks may affect market risk through asset price volatility, liquidity risk through funding pressures, and operational risk through disruptions to infrastructure (NGFS, 2020).

3.1.2 Macroeconomic transmission channels

At the macroeconomic level, climate change can influence economic growth, fiscal stability, and financial conditions. Climate shocks may reduce output, lower tax revenues, and increase public expenditure related to disaster response and climate adaptation. These effects can weaken macroeconomic stability and lead to tighter financial conditions.

In climate-sensitive economies, reduced economic activity and income volatility can increase borrower vulnerability, thereby amplifying credit risk in the banking sector. These macroeconomic effects are particularly relevant for developing economies with high dependence on agriculture and limited diversification (Buhr et al., 2018).

3.1.3 The financial macro network approach: shock propagation conceptual framework

To formalise the transmission of climate shocks across sectors, this study draws on the financial macro-network framework proposed by Stolbova and Battiston (2020), which captures both direct and indirect effects through interconnected balance sheets.

The balance sheet of an institutional sector i at time t is defined as:

$$A_i(t) = \sum_{j,k} A_{ij}^k(t) + S_i(t) \qquad (1)$$

where A_i denotes total assets, A_{ij}^k represents exposure to sector j through financial instrument k, and S_i captures other assets.

The relative exposure of sector i to sector j is given by:

$$w_{ij} = \frac{A_{ij}}{A_i}$$

A climate shock affecting sector i, denoted by $\Delta A_i(t_0)$, can propagate to sector $j$as follows:

$$\Delta A_j(t_1) = A_{ji} \cdot \frac{\Delta A_i(t_0)}{A_i} \qquad (2)$$

This formulation illustrates how shocks can spread across sectors through financial linkages, even when sectors are not directly exposed to the initial shock.

In a system of interconnected sectors, the propagation of shocks can be expressed as:

$$\Delta A_j(T) = \Delta A_i(t_0) \prod_{(m,k)\in s} w_{mk} \qquad (3)$$

While this framework provides a useful conceptual basis for understanding shock transmission, the present study focuses empirically on the direct and macro-financial channels through which temperature shocks affect banking sector stability, particularly via the credit risk channel.

3.2 Empirical literature

A nascent but growing body of literature by academics, central banks, and other international research bodies has documented the link between climate-related risks (CRRs) and the stability of the financial sectors across countries (Carè et al., 2024). It has been found that some of the new sources of risk to financial stability emanate from climate-related risks, and stakeholders have started paying attention to climate finance as a result (Battiston et al., 2021). Although the estimation of climate-related risks (CRRs) has received considerable attention, the field remains in its early stages, and no consensus has yet emerged on the most appropriate modelling approaches.

The assessment of CRRs is particularly complex due to several factors. First, significant uncertainty persists regarding the interaction between climate dynamics and economic systems. Second, the long-term horizons over which climate risks materialize complicate forecasting and scenario analysis. Third, heterogeneity across regions, sectors, and institutions challenges the development of uniform modelling frameworks. Fourth, rapid technological change introduces dynamic effects that are difficult to anticipate. Finally, the damage functions commonly employed to quantify the economic impacts of climate change remain incomplete and contested, constraining the accuracy of impact assessments. Therefore, this section documents empirical literature on the financial sector's stability in relation to climate-related risks.

Empirical evidence from developed countries, particularly the United States and Europe, indicates that climate risks, especially physical shocks, undermine banking sector resilience. For instance, (Noth and Schüwer, 2023) used U.S data covering 12,000 weather-related disasters and more than 6,000 banks to show that hurricanes and other natural hazards lead to increased non-performing loans, reduce z-scores, and heightened default probabilities. Similarly, (Schüwer et al., 2018) highlight how Hurricane Katrina significantly worsened bank-level stability indicators.

In Europe, (Ferreiro et al.,2022) employed climate transition scenarios to analyze systemic risks among 900 listed firms and 190 financial institutions. They found that a disorderly transition, particularly under high-carbon exposure, poses systemic risks, especially for Southern Europe. (Lee et al., 2024) reinforced this by demonstrating how climate mitigation policies under the Fit-for-55 framework raise default probabilities in France.

(Curcio et al., 2023) expanded the scope by examining green and brown asset indices in the U.S., showing that extreme weather and green finance volatility exacerbate systemic risk. Meanwhile, (Mandel et al., 2021) applied a network propagation model to find that in highly leveraged systems, characteristics of many developed economies, climate shocks can generate significant systemic risks.

(Li, 2023) investigated the impact of climate risk on bank profitability using a sample of Vietnamese banks. The analysis draws on panel data from 2000 to 2019, sourced from the Vietnam Household Living Standard Survey and national household statistics. The Autoregressive Distributed Lag (ARDL) model was employed to capture both short and long-term dynamics between climate risk, energy price co-movements, and financial stability. The empirical results reveal a strong relationship between financial stability, environmental sustainability, and the potential for a green economic recovery. Specifically, climate change is found to influence energy price co-movements, which in turn affect banking sector performance and broader financial stability.

The findings also indicate that modelling limitations and inaccurate estimations may exacerbate, rather than mitigate, the risks of financial instability and physical climate shocks, raising further challenges for green economic growth. Importantly, the evidence suggests that banks can enhance resilience and support the low-carbon transition by adjusting loan supply conditions based on borrowers' carbon profiles, particularly in advance of climate policy implementation. Such proactive capital allocation strategies not only align banking practices with climate objectives but also contribute to safeguarding long-term financial stability.

Also, (Fabris, 2020) proposed a nine-step framework that illustrates how climate risks can be systematically integrated into financial stability assessments. The findings reveal several important methodological insights.

First, the development of a sectoral exposure matrix. This allows for mapping the vulnerability of different sectors to climate-related risks. However, the research identifies a key methodological challenge: the lack of a universal taxonomy to define which economic activities or financial instruments qualify as environmentally sustainable ("green") or environmentally harmful ("brown"). This gap complicates the consistency and comparability of exposure assessments across jurisdictions.

Second, macroeconomic modelling is recognized as both necessary and highly complex. The methodological challenge lies in capturing the dynamic interactions between the macroeconomy, the financial system, climate change variables, and environmental policy interventions. Current modelling approaches remain limited in scope, suggesting the need for more sophisticated techniques capable of integrating these interdependencies.

Third, the classification of companies and assets according to an agreed taxonomy emerges as a crucial methodological step. The findings emphasize that firms must be able to identify, measure, monitor, manage, and disclose their climate-related exposures. This process not only enhances firm-level risk management but also provides standardized data inputs for macro-financial assessments, thereby improving the reliability of system-wide analysis.

Finally, scenario analysis is highlighted as a central methodological tool for addressing uncertainty. The findings indicate that reliance on a single scenario is inadequate for robust assessment. Instead, the development of multiple alternative scenarios strengthens the methodological foundation by capturing a wider range of plausible climate and economic outcomes. Building on this, the integration of climate risks into prudential frameworks and supervisory stress testing is considered essential. The research concludes that regulators must first establish clear supervisory expectations on governance, risk management, and provisioning before meaningful stress testing can be implemented. This ensures methodological consistency across institutions and enhances the credibility of climate-related financial stability assessments.

Emerging evidence from developing countries underscores similar vulnerabilities. (Lang et al., 2023) show that climate risks heighten liquidity stress in 23 emerging markets, weakening financial resilience. (Lee et al., 2023) extend this across 109 countries and found robust negative effects of climate risk on financial stability.

The study by (Liu et al., 2021) assesses the gap in existing literature on the impact of climate change on financial stability by using China as the research context. Second, the paper also investigated the asymmetric transmission effects of climate change on financial stability, distinguishing between short-term and long-term impacts. And thirdly, the study adopted the Nonlinear Autoregressive Distributed Lag (NARDL) model for empirical testing, which is particularly robust when applied to small sample sizes.

(Liu et al., 2021) conceptualized climate change as long-term alterations in the state of the climate, commonly measured through temperature variations. Accordingly, the average temperature was employed as a proxy variable for climate change. The dataset comprised monthly observations from 173 basic and reference surface meteorological stations, as well as automatic observation stations, spanning the period from 2002 to 2018. These data are sourced from the "Monthly Report of Surface Meteorological Records," compiled by climate data processing departments across 30 provinces in China. By using the average monthly data from all 173 stations, the study effectively captures the temporal and spatial variations in China's temperature, providing a reliable proxy for analyzing the effects of climate change on financial stability.

The findings revealed that climate shocks, whether positive or negative, can affect financial stability. In the short term, positive climate shocks had a stronger immediate impact on financial stability than negative shocks; however, this effect weakened over subsequent periods. In contrast, over the long term, negative climate shocks led to more pronounced adjustments in financial stability compared to positive shocks. Overall, the results indicated that climate change exerted a greater and more persistent destabilizing effect in the long run than in the short term, underscoring its enduring threat to the financial system.

In Sub-Saharan Africa and other developing regions, while empirical studies remain sparse, early findings suggest that climate variability heightens credit default risk in agriculture and small enterprise lending, which are areas that are most vulnerable to environmental shocks (Feyen et al., 2021). Also, (Aloui *et al*; 2023) explored the macro-financial externalities of environmental degradation in Africa. The paper specifically examined whether and how changes in non-renewable and renewable energy consumption affected financial instability in 35 sub-Saharan African (SSA) countries. An original econometric approach was employed, combining panel logit-probit models with bootstrap inference for quantile regressions to investigate the occurrence of systemic banking crises as an indicator of extreme financial instability from 1990–2018, and the quantile function of the banking sector stability index (Z-score) as a measure of varying levels of banking instability from 1990–2021.

The empirical results supported the climate fragility hypothesis, showing that increases in both non-renewable and renewable energy consumption were associated with a higher probability of systemic banking crises and a decline in banking stability, particularly in the lower quantiles representing extreme instability. These effects were primarily driven by transition and physical risks related to climate change in SSA countries.

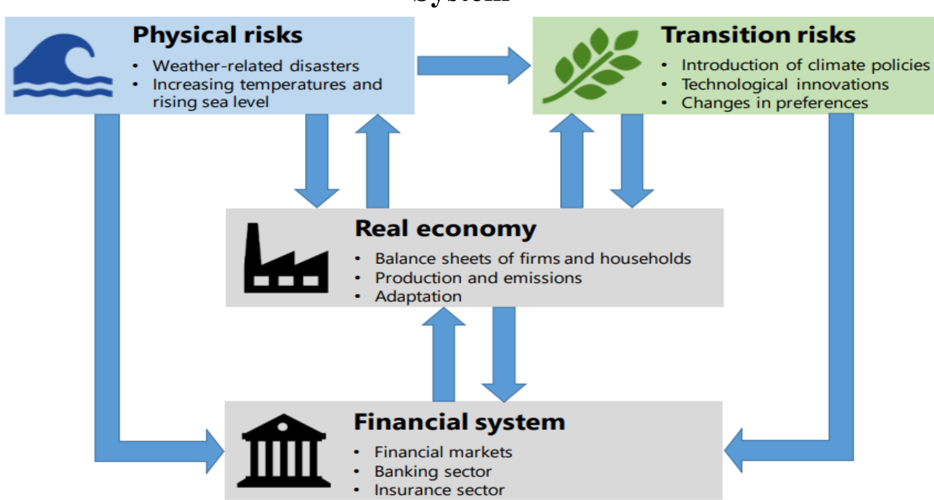
Methodologically, most studies use panel regression techniques such as fixed effects or dynamic GMM estimators to account for unobserved heterogeneity and serial correlation (Cevik and Jones, 2020; Beirne et al., 2021). Local Projection (LP) methods are increasingly employed to estimate impulse response functions over multiple horizons, providing a flexible approach to capturing non-linear dynamics. The issue of endogeneity, especially between macroeconomic variables and climate indicators, is often addressed using instrumental variables or lagged regressors, though the robustness of these instruments varies. In recent literature, mediation analysis and structural vector autoregressions (SVARs) have also been used to unpack indirect transmission channels through GDP or inflation (Beirne et al., 2021; Ndum and Nwokoro, 2024).

Climate risk measurement varies widely. Some studies use weather anomaly data (e.g., temperature deviation), disaster records (EM-DAT), and transition risk indicators such as carbon pricing policies or firm-level ESG scores. Financial data typically comes from bank balance sheets, supervisory datasets, or financial stability reports. However, challenges persist, especially in developing countries, due to data gaps, limited firm-level ESG coverage, and inconsistent climate risk definitions (OECD, 2021).

Despite the growing consensus, controversies remain. Some argue that market participants have already priced in climate risks, reducing their threat to stability (Bolton et al., 2020). Others highlight uncertainty in climate projections, suggesting caution in integrating them into regulatory stress testing (NGFS, 2020). Moreover, the non-linear and long-run nature of climate effects complicates causal identification.

Nonetheless, the empirical literature underscores that climate change poses significant risks to financial stability across both developed and developing countries. While methodologies and data availability vary, the consensus is that integrating climate considerations into financial decision-making is imperative. Addressing data gaps, enhancing institutional capacities, and ensuring equitable climate finance are critical steps towards building resilient financial systems in the face of climate change.

Figure 7: The schematic view of the link between climate change risks and the Financial System



Source: (Furukawa et al., 2020)

4 Data and Methodology

4.1 Data Sources and variable description

The study employs an annual panel dataset covering the period 2009 to 2023 for three Common Monetary Area (CMA) member countries: Lesotho, Namibia, and Eswatini. These economies are characterized by relatively high exposure to physical climate risk and strong links between climate-sensitive activity (particularly agriculture and related value chains) and household and firm income, making them a suitable setting for assessing how temperature variability may transmit to banking sector stability.

The dataset combines temperature change data sourced from the Food and Agriculture Organization (FAO) with financial soundness indicators obtained from the International Monetary Fund data portal. Macroeconomic variables, including GDP growth and lending interest rates, are obtained from the World Bank Development Indicators (WDI). Structured by country-year observations, the panel enables dynamic estimation using the Linear Projections Model to trace the impulse response of changes in non-performing loans to temperature shocks over a five-year horizon. The study period is determined by data availability. Table 1 presents variable definitions, expected relationships, and data sources.

Table 1:Description of Variables

Variable	*Definition/Measurement*	*Expected Relationship*	*Source*
Dependent Variable: Non-performing Loans (NPLs)	*Ratio of non-performing loans to total gross loans (%)*	-	*IMF Financial Soundness Indicators (FSI)*
Independent Variables			
Temperature change	*Annual mean temperature anomaly (°C), proxy for physical climate risk*	*Positive (+) — higher temperatures increase physical climate risk, reduce productivity, and repayment capacity*	*FAOSTAT Climate Change Indicators*
GDP growth	*Annual real GDP growth rate (%) capturing macroeconomic conditions*	*Negative (–) — stronger economic activity improves borrower income and reduces defaults*	*World Bank World Development Indicators (WDI)*
Capital to Assets ratio	*Regulatory capital as a percentage of total assets (%), measuring bank solvency.*	*Negative (–) — better capitalization improves bank resilience and credit risk management.*	*IMF Financial Soundness Indicators (FSI)*
Lending interest rates	*Average lending interest rate (%) reflecting borrowing costs*	*Positive (+) — higher borrowing costs increase debt servicing burden and default risk*	*World Bank World Development Indicators (WDI)*
Provisions to non-performing loans	*Loan-loss provisions relative to non-performing loans (%) indicate risk recognition.*	*Negative (–) — stronger provisioning reflects better risk coverage and loss absorption.*	*IMF Financial Soundness Indicators (FSI)*
Liquid assets	*Liquid assets as a percentage of total assets (%), measuring liquidity buffers.*	*Negative (–) — higher liquidity strengthens buffers and reduces vulnerability to shocks*	*IMF Financial Soundness Indicators (FSI)*

Note: The signs reflect the expected relationship between each independent variable and the dependent variable. A positive (+) sign indicates an expected increase in NPLs (deterioration in asset quality), while a negative sign (-) indicates an expected decline in the NPLs (improvement in asset quality).

4.2 Empirical Model Specification

4.2.1 Local Projection Approach

This study employs the Local Projections (LP) approach introduced by Jordà (2005) to estimate the dynamic response of banking sector stability to temperature shocks. The LP method is well-suited to the climate–finance context because it provides flexible impulse-response estimation without imposing the strong dynamic restrictions typical of vector autoregression (VAR) models. It is also more robust to potential model misspecification and can accommodate richer specifications that include fixed effects, lag structures, and additional controls (Jordà, 2005; Olea and Plagborg-Møller, 2021).

Given the relatively small panel dimension in this study, the analysis focuses on a five-year horizon, which captures short-, medium-, and longer-run dynamics while preserving sufficient degrees of freedom for estimation at each horizon. The LP method estimates impulse response functions (IRFs) by running separate regressions for each horizon *h=1,,5.* Specifically, following a temperature shock at time *t*, the model estimates its effect on banking sector stability at *t*+h. The sequence of estimated horizon-specific coefficients β_h is then plotted to obtain the impulse response profile across horizons, allowing the analysis to distinguish short-run, medium-run, and longer-run dynamics.

4.2.2 Baseline Equation/Estimation approach

To estimate the impact of temperature change on banking sector stability (NPL ratio), we employ the LPM. The dependent variable is the NPL ratio, measured between $t - 1$ and $t + h$. The main independent variable is the temperature change, which then serves as a measure of how climate change can affect banks' performance.

The equation also includes the lags of the explanatory variables, as well as the lags of the dependent variable. The LP model for estimating the impulse response function for country i at horizon h is given by:

$$\Delta NPL_{i,t+1} = \alpha_{i,h} + \tau(h)_t + \beta_h \Delta T_{i,t} + \sum_{s=1}^{p} \gamma_{h,s} T_{i,t-s} + \sum_{s=1}^{p} \delta_{h,s} NPL_{i,t-s} + \gamma_h{}' BSF_{it} + \theta_h{}' Mac_{it} + \varepsilon(h)_{t,i}$$

Where:

- $\Delta Y_{i,t+h,}$ = Change in NPLs, serving as a proxy for banking stability.
- $\alpha_i(h)$ and $\tau(h)_t$ = Country and time-fixed effects, controlling for country-specific and time-specific shocks.
- $T_{i,t-1}$ = Temperature change shock
- β_h = This is the impulse response function of the dependent variable with respect to $T_{i,t-1}$, which is the main coefficient of interest
- $\Upsilon_{h,s}$ and $\delta_{h,s}$ = Lag values of both the temperature change and NPL ratio, respectively, allowing for persistent effects from past events. The number of lags is denoted by p

- BSF_{it} and Mac_{it} are the bank-specific and macroeconomic factors affecting the stability of banks
- $\varepsilon(h)_{t,i}$ = error term

Similarly, following (Nie, Regelink, and Wang 2023), the bias that may be caused by contemporaneous interaction between financial sector variables and climate change has been accounted for by including the lagged bank-specific variables as controls. One of the reasons to include the lagged financial sector variables is that, when the primary interest is in assessing the impact of climate change on the banking sector stability, the immediate (contemporaneous) interactions could be noise rather than a true long-term effect. Therefore, financial variables may respond to climate events in the short term, but this does not necessarily imply a causal relationship. Also, climate change effects are often long-term phenomena. Short-term fluctuations in financial markets due to extreme weather events or policy shifts may not reflect the structural impact of climate risks on financial stability. Dismissing contemporaneous interactions could help focus on persistent changes rather than temporary market reactions.

Table 2: Summary Statistics

	Mean	Maximum	Minimum	Std.dev	Skewness	Kurtosis
NPL	4.78	10.67	1.29	2.62	0.56	-0.73
TEMP	0.78	2.27	-0.36	0.49	0.44	0.56
GDP	2.11	10.68	-8.10	3.46	-0.67	1.32
Capital/Assets	9.88	17.53	4.49	2.78	0.07	-0.08
Lending rates	4.24	11.90	-3.24	3.60	0.10	-0.71
Provisions	48.26	91.37	18.75	16.26	0.34	0.01
Liquidassets	8.98	23.76	4.06	4.60	1.52	1.92

Source: Authors' computation using R-studio. NPL denotes non-performing loans to gross loans (%), TEMP denotes Temperature change (degrees Celsius), GDP indicates GDP growth (annual %), Capital/Assets ratio (%), Lending interest rates (%), provisions denote the ratio of provisions to non-performing loans, and liquidassets denotes the ratio of liquid assets to total assets.

Table 2 presents summary statistics for the main variables used in the analysis. The average non-performing loan (NPL) ratio is 4.78 percent, with values ranging from 1.29 to 10.67 percent and a standard deviation of 2.62, indicating moderate variation in asset quality across countries and over time. The slight positive skewness suggests that periods of elevated credit stress occur intermittently within the sample.

Temperature change exhibits a mean of 0.78 with relatively low dispersion, reflecting gradual warming trends rather than abrupt climate shifts during the sample period. GDP growth averages 2.11 percent but displays considerable volatility, with a range from − 8.10 to 10.68 percent. The negative skewness indicates that economic downturns occur more frequently than unusually strong expansions, highlighting exposure to macroeconomic shocks in the region.

Among banking sector indicators, the capital-to-assets ratio averages 9.88 percent, suggesting generally adequate capitalization, while the moderate dispersion indicates relatively stable capital buffers. Loan-loss provisions exhibit substantial variability, reflecting differences in credit risk recognition and provisioning practices across time and jurisdictions. Lending rates show notable variation, consistent with changing monetary and financial conditions, while liquid assets indicate differences in liquidity management across banking systems. Overall, the descriptive statistics suggest meaningful variation in both climate and financial variables, supporting the empirical analysis of dynamic relationships.

5 Empirical results

This section presents the empirical findings on the dynamic relationship between temperature variability and banking sector stability in Lesotho, Namibia, and Eswatini. Using the Local Projection framework, the analysis evaluates how temperature shocks affect changes in non-performing loans across short-, medium-, and longer-term horizons.

The correlation matrix (Table 3) indicates generally weak to moderate correlations among variables, suggesting that multicollinearity concerns are limited and supporting the suitability of the variables for regression analysis.

Table 3: Correlation Matrix

	NPL	TEMP	GDP	Capital/Assets	Lending rates	Provisions	Liquid assets
NPL	1.00						
TEMP	-0.01	1.00					
GDP	0.04	−0.20	1.00				
Capital/Assets	0.39	−0.03	−0.02	1.00			
Lending rates	0.21	0.37	0.02	−0.02	1.00		
Provisions	−0.30	−0.26	−0.08	−0.28	0.04	1.00	
Liquid assets	0.59	0.03	0.12	0.42	0.12	0.04	1.00

Source: Authors' computation using R-studio. NPL denotes non-performing loans to gross loans (%), TEMP denotes Temperature change (degrees Celsius), GDP indicates GDP growth (annual %), Capital/Assets ratio (%), Lending interest rates (%), provisions denote the ratio of provisions to non-performing loans, and liquid assets denote the ratio of liquid assets to total assets.

To assess the stationarity of the variables used in the study, panel unit root tests were conducted using the Im–Pesaran–Shin (IPS) and Fisher-type Augmented Dickey–Fuller (ADF) approaches, as shown in Table 4. The results indicate that most variables are stationary in levels, while the non-performing loans (NPLs) are found to be stationary in differenced form. For the provisions variable, the IPS test suggests stationarity, whereas the ADF test provides weaker evidence, indicating potential persistence. To address this ambiguity and mitigate concerns related to non-stationarity and simultaneity, the study incorporates lagged provisions rather than contemporaneous values, consistent with the Local Projection framework, which allows lag structures to capture gradual adjustment dynamics while ensuring robust estimation.

Table 4: Unit Root Tests

	IPS			ADF		
Variables	**Level**	**First difference**	**Order of integration**	**Level**	**First difference**	**Order of integration**
NPL		-4.01***	I(1)		39.09**	I(1)
TEMP	-3.63***		I(0)	18.87 **		I(0)
GDP	-4.37***		I(0)	12.51·		I(0)
Capital/Assets	-3.63***		I(0)	37.32**		I(0)
Lending rates	-3.99***		I(0)	17.47**		I(0)
Provisions	-3.45***		I(0)	6.01		-
Liquid assets	-1.59*		I(0)	14.24***		I(0)

*Note: IPS means lm-Pesaran_Shin (IPS) and ADF as Fisher ADF (Maddala–Wu), p-value significance levels: * p < .05, ** p < .01, *** p < .001. p < .10*

To ensure the validity of the empirical specification, a range of diagnostic tests were conducted, including tests for heteroskedasticity, serial correlation, functional form misspecification, and multicollinearity. Therefore, the study used heteroskedasticity-consistent standard errors to ensure robust results. Detailed diagnostic results are reported in Appendix A.

6 Empirical results

Table 5 reports the regression estimates, while Figure 8 presents the impulse response functions illustrating the dynamic adjustment of credit risk following temperature shocks.

Table 5: Table Regression results

Variable	Model 1 (year 1)	Model 2 (year 2)	Model 3 (year 3)	Model 4 (year 4)	Model 5 (year 5)
(Intercept)	11.01	-26.17	-46.10	45.59	-42.39
	(6.82)	(9.17)	(8.23)	(5.78)	(7.07)
TempChange	2.68***	-0.70	4.45**	-2.82**	2.02
	(0.48)	(1.03)	(1.10)	(0.59)	(0.66)
lag_TempChange	-2.51**	1.54	4.55**	-5.14**	5.98**
	(0.65)	(0.93)	(0.76)	(0.60)	(0.67)
GDP	-0.49**	0.44*	-0.06	-0.01	0.28
	(0.13)	(0.17)	(0.14)	(0.08)	(0.10)
log(CapitalAssets)	4.03***	-2.96*	9.06***	-7.72***	5.47**
	(0.63)	(0.89)	(1.05)	(0.67)	(0.64)
RATEs	0.11	-0.26*	-0.27*	0.25**	-0.21
	(0.05)	(0.10)	(0.09)	(0.05)	(0.08)
log(Provisions)	-1.01	7.28**	0.46	2.23	-0.58
	(1.20)	(1.74)	(1.39)	(0.95)	(1.06)
log(LiquidAssets)	3.43**	-3.59*	7.14**	-4.98**	-2.93*
	(0.67)	(0.98)	(1.11)	(0.61)	(0.91)
lag_CapitalAssets	-0.83***	0.80**	0.38*	-0.55**	0.70**
	(0.14)	(0.18)	(0.14)	(0.11)	(0.12)
lag_LiquidAssets	-0.43***	0.07	0.23	-0.92**	1.19**
	(0.06)	(0.19)	(0.18)	(0.13)	(0.15)
lag_Provisions	0.11**	-0.13*	-0.15**	0.28***	-0.24**
	(0.02)	(0.04)	(0.04)	(0.03)	(0.023
lag(dNPLs,1)	0.65***	-0.65**	-0.39*	0.78**	-0.55*
	(0.09)	(0.17)	(0.13)	(0.12)	(0.14)
lag(dNPLs,2)	0.03	-0.10	-0.27	0.22*	0.18
	(0.06)	(0.14)	(0.13)	(0.07)	(0.08)
Country: Lesotho	-5.52**	0.34	11.11**	-18.68***	14.88**
	(1.06)	(2.48)	(2.64)	(1.82)	(1.96)
Country: Namibia	-2.01*	-0.67	7.92**	-10.61***	8.55**
	(0.72)	(1.69)	(1.69)	(0.96)	(1.05)
Year Effects	Yes	Yes	Yes	Yes	Yes

Source: Authors' computation using R-studio. NPL denotes Non-performing loans to gross loans (%), TEMP denotes Temperature change (degrees Celsius), GDP indicates GDP growth (annual %), Capital/Assets ratio (%), Lending interest rates (%), provisions denote the ratio of provisions to non-performing loans, and liquidassets denotes the ratio of liquid assets to total assets. Note: Values are regression coefficients; numbers in parentheses are standard errors.
*p-value significance levels: * p < .05, ** p < .01, *** p < .001, . p < .10*

6.1 Results and Discussion

6.1.1 Short-run effects (Year 1)

The short-run results indicate that temperature shocks exert an immediate and statistically significant impact on changes in NPLs. In the first year, the coefficient on temperature change is positive and highly significant, implying that temperature increases are associated with a rise in credit risk in the immediate period. These findings support the physical risk channel, whereby temperature increases disrupt economic activity, reduce agricultural output, and weaken borrower repayment capacity in climate-sensitive economies such as Lesotho, Namibia, and Eswatini.

The impulse response function (see Figure 8) corroborates this evidence by showing an initial upward response of change in NPLs following a temperature shock, indicating that credit risk deteriorates shortly after the shock materializes. This pattern is consistent with the literature documenting that physical climate shocks can impair firm performance and increase default risk through their effects on productivity and cash flows (Addoum et al., 2020; Battiston et al., 2017), reinforcing the view that temperature variability represents a material source of short-term financial vulnerability.

The negative and significant coefficient on lagged temperature change suggests partial short-term adjustment following an initial shock, potentially reflecting temporary coping mechanisms such as income smoothing, government support measures, or loan restructuring. Similar short-term dynamics have been documented by (Addoum et al., 2020), who show that temperature shocks can immediately affect firm performance and credit outcomes.

Macroeconomic conditions appear to mitigate short-term credit deterioration. GDP growth is negative and significant, indicating that stronger economic activity helps reduce increases in credit risk by supporting income and repayment capacity, consistent with the findings of (Nkusu, 2011). Interest rates exhibit weaker short-run effects, suggesting that climate shocks dominate monetary transmission in the immediate period.

Bank balance sheet variables reveal important short-term adjustments dynamics. Higher capital ratios and liquidity levels are associated with increases in changes in NPLs. While this may appear counterintuitive, the results likely reflect reverse causality and precautionary behavior, whereby banks respond to emerging credit risks by strengthening their capital and liquidity buffers. This implies that higher capital and liquidity ratios coincide with increases in NPLs contemporaneously, rather than causing the deterioration in asset quality.

Consistent with this interpretation, the lagged values of capital and liquidity are negative and statistically significant, indicating that stronger balance sheet buffers contribute to reducing credit risk in subsequent periods. This highlights the stabilizing role of capital and liquidity over time, even though their contemporaneous relationship with NPLs reflects short-term adjustments dynamics. The positive and significant persistence in lagged changes in NPLs confirms that credit deterioration tends to carry forward over short horizons.

Overall, the short-run results suggest that climate shocks quickly translate into financial stress, with banks responding through balance sheet adjustments.

6.1.2 Medium-run effects (Years 2 and 3)

In the medium run, the effects of temperature shocks become more nuanced but remain economically meaningful. While the contemporaneous temperature effect weakens at year 2, the coefficients on temperature and lagged temperature become positive and statistically significant at year 3, indicating the delayed transmission of climate shocks into credit risk. This pattern suggests that climate impacts unfold gradually through channels such as declining productivity, reduced investment, and cumulative income losses. The impulse response function (see Figure 8) supports this interpretation by showing that the response of change in NPLs remains elevated beyond the initial period, reflecting persistence in the effects of temperature shocks as they propagate through macroeconomic and financial channels. This gradual adjustment is consistent with evidence that climate shocks can have lagged effects on borrower solvency and financial stability as economic disruptions accumulate over time (Battiston et al., 2017; NGFS, 2021).

The positive and significant effects of temperature at these horizons align with the notion that climate shocks can have lagged effects on borrower solvency, as documented by Battiston et al. (2017), who highlight how climate risks propagate through financial systems over time.

Macroeconomic dynamics also evolve across time. GDP effects weaken in the medium term, while interest rates turn negative and significant in some years, suggesting that tighter monetary conditions may contribute to improving credit discipline and moderating credit risk.

Bank-specific variables continue to play a stabilizing role. Strong capital positions remain positively associated with changes in NPLs in certain years, which may reflect banks accumulating capital during periods of rising credit risk. Liquidity remains significant, indicating that balance sheet strength remains an important buffer against climate-related shocks. Provisioning dynamics suggest ongoing risk recognition as banks adjust to evolving credit conditions.

These findings underscore that climate shocks have persistent effects that materialize gradually as economic and financial adjustments take place.

6.1.3 Long-run effects (Years 4 and 5)

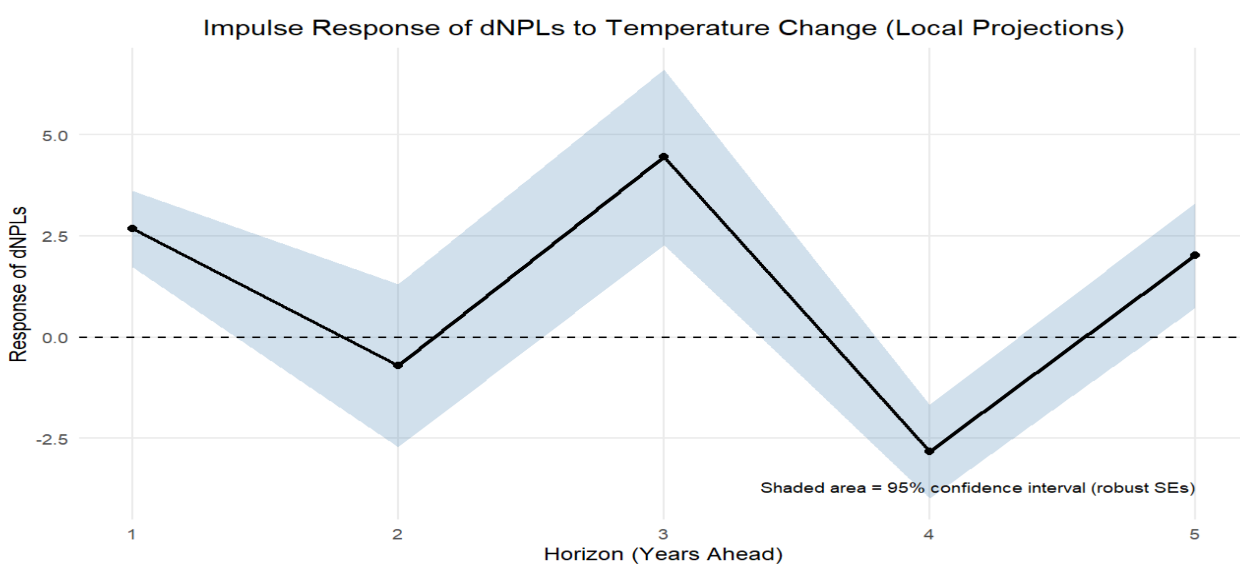
In the long run, the results reveal evidence of both persistence and adaptation. In the fourth year, temperature coefficients turn negative and significant, suggesting that after an initial period of deterioration, credit conditions may partially stabilize. This could reflect adaptation mechanisms such as improved risk management, structural adjustments in economic activity, or policy responses aimed at mitigating climate impacts. The impulse response function (see Figure 8) corroborates this pattern by showing a gradual moderation in the response of change in NPLs at longer horizons, indicating that while the initial shock raises credit risk, its effects begin to dissipate over time. Such dynamics are consistent with the literature highlighting that financial systems adjust to climate shocks through learning, portfolio rebalancing, and policy interventions, which can dampen long-term impacts (Bolton et al., 2020; NGFS, 2021).

However, in year five, the positive and significant coefficient on lagged temperature change indicates that climate pressures continue to influence credit risk, highlighting the long-lasting nature of physical climate risks. This pattern suggests that while short-term recovery may occur, underlying vulnerabilities remain.

GDP effects are weaker in the long run, while interest rates show negative effects, implying that tighter financial conditions may help stabilize asset quality over time. Bank capital and liquidity buffers remain important determinants of credit dynamics, reinforcing the role of prudential strength in absorbing shocks. Provisioning behavior continues to reflect ongoing credit risk management as banks adjust to evolving conditions.

The persistence of credit risk across the five years is consistent with the broader literature emphasizing that climate risks are slow-moving but systemic in nature (NGFS, 2021; Bolton et al., 2020).

Figure 8: Impulse Response of NPLs to Temperature Changes



Source: Authors' computation using R-studio

6.1.4 Structural and temporal effects

The country fixed effects reveal structural differences in credit risk dynamics across the three economies, reflecting variations in economic structure, financial resilience, and exposure to climate-sensitive sectors such as agriculture. The significance of year effects indicates the influence of common regional shocks, including macroeconomic fluctuations, drought episodes, spillovers from South Africa within the Common Monetary Area, and global disruptions such as the COVID-19 pandemic.

These results also suggest that climate shocks interact with both country-specific vulnerabilities and broader macroeconomic conditions, reinforcing the importance of accounting for structural heterogeneity when assessing climate-related financial risks.

6.2 Synthesis of empirical results

Taken together, the results indicate that temperature shocks exert a dynamic and persistent influence on banking sector stability in Lesotho, Namibia, and Eswatini. In the short run, increases in temperature are associated with rising changes in non-performing loans, reflecting the immediate impact of climate shocks on borrower repayment capacity through disruptions to economic activity, particularly in climate-sensitive sectors.

In the medium term, the re-emergence of positive and significant temperature effects points to delayed transmission, as cumulative economic losses and macro-financial adjustments materialise. The significance of lagged temperature further highlights the persistence of climate pressures.

Over longer horizons, the results suggest partial stabilisation alongside continued lagged effects, indicating adaptation in the presence of underlying vulnerabilities. The impulse response analysis (Figure 8) supports this overall pattern by illustrating an initial increase in credit risk followed by fluctuations across horizons, consistent with gradual adjustment. Significant country and year effects further indicate that climate risks interact with structural differences and common regional shocks, reinforcing the conclusion that temperature variability remains a sustained source of financial risk in Southern African banking systems.

7 Conclusion and Recommendations

This study examined the dynamic relationship between temperature change and banking sector stability in Lesotho, Namibia, and Eswatini using a Local Projections framework. By modelling changes in NPLs, the analysis captures how physical climate shocks propagate through credit risk over time. The empirical results provide evidence that temperature increases are associated with higher credit risk, particularly in the short run and at selected medium-term horizons. The persistence observed in lagged temperature effects and lagged changes in NPLs indicates that climate shocks can generate cumulative financial stress rather than purely temporary fluctuations. Bank-specific variables play an important moderating role, suggesting that stronger balance sheets enhance resilience to climate-related shocks. The presence of significant country and year effects further highlights that climate risks operate within structurally different financial systems and are influenced by common regional macroeconomic conditions.

The policy implications of the findings point to the need for targeted measures that strengthen the resilience of banking systems in Lesotho, Namibia, and Eswatini to physical climate risks. First, supervisors should integrate climate-related physical risk considerations into credit risk assessment frameworks. Enhancing sectoral risk monitoring would improve early identification of vulnerabilities. Second, strengthening prudential buffers remains essential. Supervisory authorities should therefore ensure that banks maintain adequate buffers, particularly where exposures to agriculture and other climate-sensitive sectors are significant. Incorporating climate risk considerations into supervisory review processes would support this objective.

Third, climate-informed stress testing should be strengthened, as climate risks evolve gradually and may not be captured by static assessments. Central banks should incorporate temperature and drought scenarios into stress testing frameworks to better assess financial stability risks. Fourth, improving data availability and risk monitoring is essential. Better sectoral exposure and climate risk data would enhance vulnerability assessments, support evidence-based policies, and strengthen regional cooperation in monitoring climate-related financial risks. Lastly, coordinated policies that reduce borrower vulnerability in climate-sensitive sectors would strengthen banking resilience. Supporting climate adaptation, such as risk mitigation in agriculture, can limit the transmission of climate shocks to credit risk.

In conclusion, this study provides a timely and regionally grounded contribution to the understanding of climate change and financial stability in Southern Africa. By demonstrating how rising temperatures increase credit risk over time and by highlighting the moderating roles of macroeconomic and structural variables, it makes the case for urgent policy action. Climate change is not only an environmental challenge but also a threat to financial stability. Addressing it requires forward-looking regulation, targeted support mechanisms, institutional coordination, and sustained investment in climate data and risk analytics. These efforts will be crucial in safeguarding financial sector resilience and promoting sustainable development in countries in Southern Africa.

8 Limitations and Future Research

While this study provides timely evidence on the effects of temperature changes on banking stability in Lesotho, Namibia, and Eswatini, several limitations apply. The small, undiversified nature of these economies limits generalizability to the Southern African countries at large, and the use of aggregate national data masks subnational vulnerabilities, particularly in climate-sensitive rural areas. Temperature serves as a narrow proxy for physical climate risk, excluding floods, droughts, and transition risks. Methodologically, longer-horizon estimates may be imprecise given the short sample period (2009–2023). Future research should expand country coverage, incorporate additional climate indicators, and use sectoral or subnational data to better capture localized climate-financial dynamics to better inform climate-resilient macroprudential frameworks.

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Appendix A — Pre-estimation diagnostics test results

Multicollinearity test results measured by the Variance Inflation Factor (VIF)

Variable	Year 1	Year 2	Year 3	Year 4	Year 5
TempChange	2.53	2.92	3.89	4.28	3.93
lag_TempChange	3.12	3.53	3.88	3.42	4.07
GDP	4.06	4.02	4.17	3.75	3.78
log(CapitalAssets)	2.15	2.38	3.02	3.49	3.61
RATEs	3.76	2.25	2.53	2.62	2.57
log(Provisions)	3.01	3.93	3.94	4.02	4.41
log(LiquidAssets)	3.56	3.17	3.43	4.07	4.69
lag_CapitalAssets	2.80	3.89	3.12	4.58	4.79
lag_LiquidAssets	3.28	2.86	3.76	3.23	3.47
lag_Provisions	2.44	3.58	2.48	4.13	4.37
lag(dNPLs, 1)	2.37	2.45	2.36	2.53	2.79
lag(dNPLs, 2)	2.90	2.36	3.35	2.38	2.69
factor(Country)	1.50	2.99	1.62	3.58	3.64
factor(Year)	1.47	1.56	1.583	1.64	1.69

Note: The Variance Inflation Factor (VIF) test evaluates the extent of multicollinearity among regressors. Since all VIF values are below the conventional threshold of 5 across horizons, there is no evidence of problematic multicollinearity, supporting the stability and reliability of the coefficient estimates.

Breusch-Pagan Test Results Across Horizons

Year	Breusch-Pagan Test p-value	Heteroscedasticity Presence (at 5%)
1	0.32	No
2	0.28	No
3	0.37	No

Year	Breusch-Pagan Test p-value	Heteroscedasticity Presence (at 5%)
4	0.53	No
5	0.43	No

Note: The null hypothesis of the Breusch-Pagan test is that the error variance is constant (homoskedasticity). Since all p-values are greater than 0.05, we fail to reject the null hypothesis at 5% significance level and conclude that there is no evidence of heteroskedasticity across all horizons.

Serial Correlation Test Results

Year	Durbin-Watson Test p-value
1	0.07
2	0.13
3	0.20
4	0.76
5	0.67

Note: The null hypothesis of the Durbin–Watson test is that there is no first-order autocorrelation in the residuals. Since all p-values are greater than 0.05, we fail to reject the null hypothesis, indicating no evidence of serial correlation across all horizons.

Ramsey RESET Test Results

Year	p-value	Conclusion
1	0.04	No evidence of misspecification
2	0.48	No evidence of misspecification
3	0.26	No evidence of misspecification
4	0.56	No evidence of misspecification
5	0.16	No evidence of misspecification

Note: The Ramsey RESET test examines whether the model suffers from functional form misspecification by testing whether nonlinear combinations of the fitted values add explanatory power. The null hypothesis is that the model is correctly specified. Since the p-values are greater than conventional significance levels, we fail to reject the null hypothesis, indicating no evidence of functional form misspecification across most horizons.