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# The impact of climate change on the resilience of banking systems in selected Sub-Saharan economies

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## Abstract

Climate change is seen as a peril to the overall financial system, yet this revelation is in its infant stage. On that note, this study investigates the impact of climate change shocks on banking system resilience in selected Sub-Saharan economies. The study relies on a quantitative research method by first employing a Generalized Auto Regressive Conditional Heteroskedasticity (GARCH) (1,1) model to forecast the volatility series of the climate change variables. Further, the study applies the panel ARDL model to disseminate the long- and short-term associations between the obtained conditional variances of climate change parameters and banking system resilience within a time frame of 1996-2017 for 29 selected economies. The results show that banking systems in SSA are resilient to temperature shocks in the long-term. However, the study finds that the banking systems in SSA are not resilient to both precipitation and greenhouse gas shocks in the long-term. For the short-term impact assessment, the study finds that banking systems in SSA are resilient to only precipitation shocks. The study concludes that banking sectors in SSA should vigorously conduct stress-testing on climate-related financial risks and also design forward-looking strategies as well as climate change risk management procedures in the wake of climate change events.

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## 1. Introduction

In today's world, climate change has become a global concern, with numerous recommendations to help guide sustainability issues. That notwithstanding, concerns about the severe challenges of climate change are significant across various sectors of the economy. The rise of the climate-related concerns within the financial industry has prompted the need for empirical investigation to comprehensively explore numerous aims that could enhance global financial systems. Generally, the banking system operates within the environment, and as such, any detrimental impact on the environment will affect the banks. In addition, Carney (2015) claims that the effect of climate change on the financial system will be significantly detrimental in comparison to the global financial crisis in 2008 and other impacts such as the COVID-19 pandemic, which halted the activities of global financial markets (Agbloyor, Dwumfour, Pan, & Yawson, 2021). Against this notion, the resilience of global financial systems has been tested against copious uncertainties, yet there seems to be a glaring gap in the context of climate change shocks. Globally, scant evidence can account for the overall financial system's resilience and climate change repercussions. Empirically, studies by Nie, Regelink, and Wang (2023); Apergis and Apergēs (2022); Anand, Gai, Kapadia, Brennan, and Willison (2013); and Hollo, Kremer, and Lo Duca (2012) are a few studies that explicitly discuss the resilience of the financial system. Significantly, knowing the resilience of the banking sector serves as a warning for future banking crises, which can aggravate banking system fragilities (Apergis & Apergēs, 2022). Akande (2018) highlights that SSA's financial systems are mainly bank-based, coupled with weak macroeconomic foundations (Jafino, Walsh, Rozenberg, & Hallegatte, 2020). Hence, the impact of any external disturbance on the banking systems of the SSA region will be of great importance.

Further, Mlachila et al. (2013) disclose that economies in the SSA are susceptible to multiple shocks. These shocks include economic shocks, health shocks, unexpected population outflows, and extreme weather shocks. Essentially, the rise in shocks emanating from climate change has become an intricate entity in the banking sector. For some time now, financial system players have taken keen interest in designing strategies to adequately prepare against climate change shocks. On that account, the Financial Stability Board (FSB) report in 2020 expounded that financial authorities have steered procedures for banks in the view that conventional risk management processes are unfit to measure climate-related risk. In effect, climate change continues to be a global topic of discussion, of which SSA is no exception. Indeed, the question of resilience has become paramount as shocks are prevalent in the financial system. A crucial empirical search has revealed that, to date, no study has revealed the resilience status of the banking systems against climate change shocks in SSA. Whether the banking systems in SSA are resilient to climate shocks or not is somewhat of a debate with no answer in academic empirics. Therefore, this necessitates further investigation. From a policy standpoint, this investigation will provide insight on the sturdiness of the banking systems in SSA and the preparations for the climate change sequel.

The rest of the paper is organized into sections. The empirical methodology section comes after the section that discusses climate change-related issues in the banking system. The penultimate section presents the findings and discussion. The final section presents the conclusion and recommendations of the study.

## 2. Climate Change-Related Wits in the Banking System

The growing expression of the chemistry between climate change and the financial system has surged in recent years (Lagarde, 2020), and at the same time, it is very significant to expand our understanding of the way climate change affects the banking system (Furukawa, Ichiue, & Shiraki, 2020). It is worth noting that climate change repressions are of great concern to the banking sector, as their effect may be lethal to bank operations. Inspired by this revelation, diverse opinions have been shared by numerous scholars on the relationship between climate and banking system. In the banking system stability-climate change relationship, for instance, authors such as Klomp and De Haan (2014) and Noth and Schüwer (2018), as well as Schüwer, Lambert, and Noth (2019), indicate that climate change reduces banks Z-score (stability). In defiance of the aforesaid nexus, other scholars kink ideas about climate change and the credit activities of the banking system. In view of this, authors such as Koetter, Noth, and Rehbein (2020) disclose that climate change repercussions amplify non-performing loans rather than the bank's Z-score (stability). Further,Gallagher, Hartley, and Rohlin (2023) argue that delinquencies of credit cards grow in the event of climate change disasters. On the other hand, Brown, Gustafson, and Ivanov (2021) contend that smaller firms increase their credit size in the wake of climate change shocks. Besides, Dessaint and Matray (2017) uphold the discovery that economic agents strengthen their cash holdings in the event of climate change disasters. Furukawa et al. (2020) highlight that banks are adamant about lending to borrowers in the period of climate change repressions. From a clichéd point of view, Berg and Schrader (2012) establish that access to credit is limited during climate change ramifications. In addition, authors such as Koetter et al. (2020); Ivanov, Macchiavelli, and Santos (2022), Cortés and Strahan (2017) as well as Hosono et al. (2016) suggest that unaffected banks connected to affected banks of climate change impact experience weak lending capacity. As such, there is a spill-over effect from affected banks to unaffected banks.

Given the scale of the insinuations of climate change impact on the banking system, Löyttyniemi (2021) mentions that stability is a core function of central banking. The author explain that it is through the Network for Greening the Financial System (NGFS) initiative, the Financial Stability Board (FSB), Bolton, Després, Pereira da Silva, Samama, and Svartzman (2020) as well as the 2021 Bank for International Settlements (BIS) "Green Sawn" Conference that shed more seriousness on climate change as a banking sector challenge to the attention of central banks. In recent times, Bolton et al. (2020) have acknowledged that climate change policies should be a principal mandate for central banks across the globe. Interestingly, an adequate flow of capital is crucial to a well-functioning economy; however, instability caused by climate change poses systematic risks (The White House, 2021). Importantly, there is a likelihood of climate change affecting the banking system

(Batten, Sowerbutts, & Tanaka, 2016; Dafermos, Nikolaidi, & Galanis, 2018; Scott, Van Huizen, & Jung, 2017). On that account Oguntuase (2020) explains that climate change manifests itself in the banking sector as credit risk, market risk, and operational risk. In essence, climate change has the tendency to weaken banks' balance sheets (*inbid.*). Further, the State Bank of Pakistan (2021) writes that climate change translates into five major risks: they are credit risk (loan default, collateral depreciation), market risk (repricing of fixed income, equities, and commodities), operational risk (disruption of the supply chain, forced facility closure), liquidity risk (refinancing risk, upsurge demand for liquidity), and legal and reputational risk (climate-related lawsuits, providing finance to carbon-intensive businesses). Moreover, Pointner and Ritzberger-Grünwald (2019) establish in their financial stability report that the impact of climate change on banks includes operational risk (higher operating costs), systemic risk (higher asset volatility and higher risk premiums), reputational risk (downgrade in ratings, loss of clients, less employee attraction), liquidity risk (capital depletion), market risk (shifts in demand, stranded assets), and credit risk (higher probability of default).

On that note, there is little experience for banks to model the financial impacts of climate change (Kearns, 2022). Fabris (2020), on the other hand, indicates that the impact of climate change on the banking sector has three major implications. First, climate change increases bad loans. Second, climate change expedites the growth of insurance premiums. Third, climate change devalues financial instruments. Evidently, the physical impact of climate change threatens banking stability through changes in property value, supply chain disruptions, and property damage (Reserve Bank of New Zealand: Our Climate Strategy, 2023). With regards to the transitional impact of climate change, it affects policy changes and technological progression as well as changes in consumer and investor preferences (Kearns, 2022). There is a growing body of evidence suggesting that the banking system possesses the ability to support environmentally sustainable initiatives through the use of balanced technical expertise, particularly in the face of financial difficulties (Kirikkaleli & Sofuoğlu, 2023; Qayyum et al., 2023). Authors such as Claessens and Feijen (2007) establish that the growth of the banking sector creates superiority in environmental quality. Contrary to this view, Jensen, Mercer, and Johnson (1996) point out that the growth of the banking sector leads to a credit boom and industrial growth, causing environmental havoc. DeMenno (2022) reports that although climate change affects the banking system, yet the consequences remain underexplored. Again, changes in temperature could affect the value of assets, and increase credit risk for institutions (Yin, 2019), and decrease government funding (Sun, Wang, Yin, & Zhang, 2019). Nonetheless, climate change affects the central bank's capacity to achieve its monetary and financial stability goals (Deutsche Bundesbank Eurosystem: Spring Conference, 2023). Therefore, climate change is important to central banks as it has a possible impact on both monetary and financial stability (Olovsson, 2018). In recent times, various central banks have started the implementation of climate change initiatives in their assessment of future financial risks when setting monetary and financial supervisory policy (Rudebusch, 2019). Monasterolo (2020) opines that the risk associated with climate change exhibits distinct characteristics, including deep uncertainty, non-linearity, and endogeneity.

In spite of the numerous revelations on climate change, the Deputy Governor of the Bank of Italy, Luigi Frederico Signorini in his keynote address in 2017 highlighted that though financial regulators are not environmental watchdogs, yet, issues of climate change have become a pertinent subject for them. In addition, the governor of the Bank of France, Francois de Galhau (2019) mentioned in "Climate Change: central banks are taking action" mentioned that climate change could endanger prices and financial stability. Climate change has become an important priority since 2021 (U.S Department of the Treasury, 2022). In effect, Alexander and Fisher (2019) unveil that one policy response to climate change repercussions that could make the banking system resilient is extensive public information on climate-related exposures. More so, disclosure is an important policy initiative (Alexander & Fisher, 2019). That said, the authors mention that climate change is a material financial risk, and as such, minimum calculations are specified. Therefore, the rules require banks to hold capital against all material risks that the firm has identified (*inbid.*). According to Schellhorn (2020), the central bank is the climate leader of last resort; likewise, climate change can aggravate banking system stability risk(Buch & Weigert, 2021).

## 3. Empirical Methodology

### *3.1. Data*

We employed 29 selected Sub-Saharan economies from 1996 to 2017 for the present study. It should be emphasized that the choice of countries is based on data availability. See Appendix 1 for the list of countries used in this study. Data on climate change variables were obtained from two sources: the Climate Watch online platform (greenhouse gas emissions) and the World Bank Climate Knowledge Portal (temperature and precipitation). On the other hand, a climate change index was created using Principal Component Analysis (PCA) with the afore-mentioned climate change variables. Further, we create an index for banking system resilience using bank-specific indicators obtained from the World Bank Global Financial Development Database. The bank-specific variables used in creating the banking system resilience measurement include Return on Assets (ROA), Return on Equity (ROE), Net Interest Margin (NIM), and efficiency (cost-to-income ratio). In addition, the study controlled for variables such as bank deposits, bank credit-to-bank deposits, inflation and real GDP. Inflation and real GDP data were gleaned from World Development Indicators

(WDI) while bank deposits and bank credit-to-bank deposits were sourced from the World Bank Global Financial Development platform.

### 3.2. Estimation Strategy

We first apply the generalized autoregressive conditional heteroscedasticity (GARCH) model developed by Bollerslev (1986) to forecast the volatility series of the climate exposures, thus temperature, precipitation, and greenhouse gas, for individual countries, and we incorporate the series obtained into a panel ARDL model. In addition, a forecast will be done on the climate change index (CCI) to estimate its shock on banking system resilience. Ibrahim (2017) elucidates that using the GARCH model to predict the actual shocks of variables has the potential to capture historical values and the behaviour of the series. Therein, variables are subjected to a GARCH (1,1) model to obtain the volatility series of the various parameters. Therefore, the GARCH (1,1) model will be estimated as follow:

$$ln\,VEC_t = \beta_0 + \beta_1\, ln\,VEC_{t-1} + \mu_t \quad (1)$$
$$\mu_t | \Omega_t \sim iid\ \mathrm{N}(0, h_t)$$

Equation 1 presents the vector of terms for climate change parameters, which depends on the log of its one-period lag.

$$h_t = \varphi_0 + \phi\mu_{t-1}^2 + \upsilon h_{t-1} (2)$$
$$\text{Hence, } \gamma_0 > 0, \phi \geq 0 \text{ and } \upsilon \geq 0$$

Equation 2 denotes the conditional variance, $h_t$ which captures the mean ($\varphi_0$) and all information about past volatility, $\phi\mu_{t-1}^2$ represents the autoregressive conditional Heteroskedasticity (ARCH) terms and $h_{t-1}$ signifies the GARCH term, thus the past forecast error variance.

The volatility series of the climate change parameters are then incorporated into a Panel Autoregressive Distributed Lag (ARDL) framework. It is well documented that panel estimations such as pooled ordinary least squares (OLS), fixed-effect, and random-effect have underlying problems that mislead econometric outputs. On that note, Attard (2019) explains that ARDL differentiates between short-term and long-term impacts and can be applied to both long and short panels. Ultimately, the equations for the panel ARDL utilized in the study are specified as;

$$ln\,BR_{it} = \beta_i + \textstyle\sum_{k=1}^{p} \beta_{1,ik}\, ln\,BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, ln\,TEMPTs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} X_{it-k} + \mu_{it} \quad (3)$$
$$ln\,BR_{it} = \beta_i + \textstyle\sum_{k=1}^{p} \beta_{1,ik}\, ln\,BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, ln\,PPTs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} X_{it-k} + \mu_{it} (4)$$
$$ln\,BR_{it} = \beta_i + \textstyle\sum_{k=1}^{p} \beta_{1,ik}\, ln\,BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, ln\,GHGASs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} X_{it-k} + \mu_{it} \quad (5)$$
$$ln\,BR_{it} = \beta_i + \textstyle\sum_{k=1}^{p} \beta_{1,ik}\, ln\,BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, CCIs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} X_{it-k} + \mu_{it} (6)$$

We denote $i = 1,2,3 \ldots N$ and $t = 1,2,3 \ldots T. \beta_1 \ldots\ldots \beta_3$ represent the coefficients of the independent variables and the response variable. $\mu_{it}$ is the error term. In addition, the panel error correction framework is expressed below;

$$ln\,BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik}\, ln\Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, ln\Delta TEMPTs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} \Delta X_{it-k} + \delta_{1,ik}\, ln\,BR_{it-1} +$$
$$\delta_{2,ik}\, ln\,TEMPTs_{it-1} + \delta_{3,ik} X_{it} + \mu_{it} (7)$$

$$ln\,BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik}\, ln\Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, ln\Delta PPTs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik}\, \Delta X_{it-k} + \delta_{1,ik}\, ln\,BR_{it-1} +$$
$$\delta_{2,ik}\, ln\,PPTs_{it-1} + \delta_{3,ik} X_{it} + \mu_{it} \qquad (8)$$

$$ln\,BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik}\, ln\Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, ln\Delta GHGASs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} \Delta X_{it-k} + \delta_{1,ik}\, ln\,BR_{it-1}$$
$$+\delta_{2,ik}\, ln\,GHGASs_{it-1} + \delta_{3,ik}\, ln\,X_{it} + \mu_{it} \qquad (9)$$

$$ln\,BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik}\, ln\Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik}\, ln\Delta CCIs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} \Delta X_{it-k} + \delta_{1,ik}\, ln\,BR_{it-1} +$$
$$\delta_{2,ik}\, ln\,CCIs_{it-1} + \delta_{3,ik}\, ln\,X_{it} + \mu_{it} \qquad (10)$$

Where $\Delta$ represents the first difference, $\beta_1 \ldots\ldots\ldots \beta_3$ depicts the short-term coefficients. Also, $\delta_1 - \delta_3$ indicate the long-term coefficients. $BR_{it}$ is banking system resilience, which is obtained by creating a banking performance index (BPI) using the principal component approach on five variables (ROA, ROE, NIM, Z-score and efficiency). $ln\,TEMPTs_{it}$, $ln\,PPTs_{it}$, $GHGs_{it}$ and $CCIs_{it}$ denotes temperature shock, precipitation shock, greenhouse gas shock and climate change index shock, respectively. On the other hand, $X_{it}$ represent a set of control vectors such as bank-specific factors (bank deposits(lnBD), and bank credit-to-bank deposits(lnBCBD), and macroeconomic indicators such as inflation and real gross domestic product (lnINFL and lnRGDP) respectively.

The panel error correction term would be expressed as:

$$\ln BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik} \ln \Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik} \ln \Delta TEMPTs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} \Delta X_{it-k} + \sigma_{it} ECM_{it-1} + \mu_{it} \quad (11)$$

$$\ln BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik} \ln \Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik} \ln \Delta PPTs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} \ln \Delta X_{it-k} + \sigma_{it} ECM_{it-1} + \mu_{it} \quad (12)$$

$$\ln BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik} \ln \Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik} \ln \Delta GHGASs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} \ln \Delta X_{it-k} + \sigma_{it} ECM_{it-1} + \mu_{it} \quad (13)$$

$$\ln BR_{it} = \beta_i + \sum_{k=1}^{p} \beta_{1,ik} \ln \Delta BR_{it-k} + \sum_{k=0}^{q_1} \beta_{2,ik} \ln \Delta CCIs_{it-k} + \sum_{k=0}^{q_2} \beta_{3,ik} \ln \Delta X_{it-k} + \sigma_{it} ECM_{it-1} + \mu_{it} \quad (14)$$

Intuitively, $\sigma_{it}$ represent the respective error terms in the variant panel ARDL models. Ostensibly, the panel ARDL model is estimated through the pooled-mean group (PMG). Pesaran, Shin, and Smith (1997) posit that PMG syndicates both pooling and averaging coefficients. Attard (2019) explains that PMG permits the coefficients of the short-term as well as intercepts and error variances to vary spontaneously in cross-sectional units.

## 4. Findings and Discussion

As indicated in Section 3.2, the volatility clustering for the conditional variance of climate change shocks created from the GARCH (1,1) model is presented in Figure 1. It is observed that variances are not constant and are coupled with clustered fluctuations.

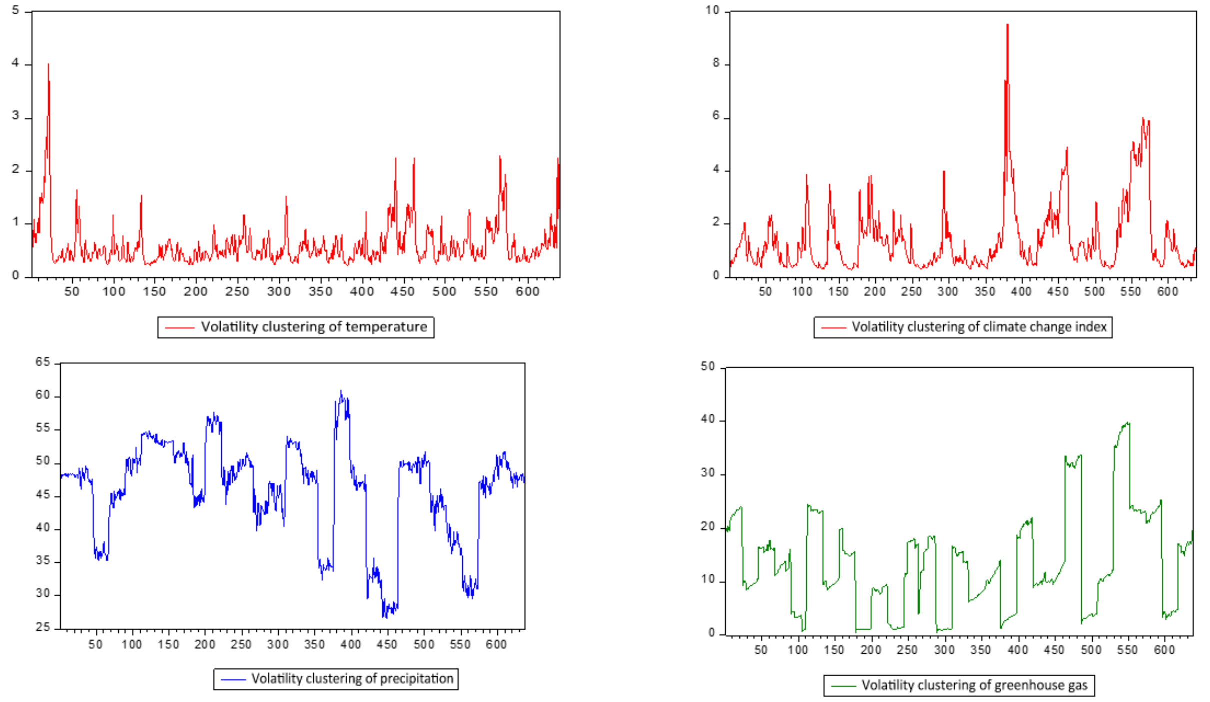

**Figure 1.** Volatility clustering of climate change variables.

We first test the stationarity properties of the variables employed in the study. Against this backdrop, the study leverages the first-generation unit root test of Levin, Lin, and Chu (2002), LLC, as well as the Im, Pesaran, and Shin (2003), IPS unit root test. Results from the unit root test at constant and constant with trend are presented in Tables 1 and 2, respectively. The findings of LLC unit root test show that some of the variables related to climate change are non-stationary in their level forms at constant and constant with trend. This includes the temperature shock, precipitation shock, and greenhouse gas shock. Similarly, the ratio of bank credit to bank deposits was non-stationary in its level form. From the IPS unit root test displayed in Table 2, it is observed that greenhouse gas shock was non-stationary in its level form at both constant and constant with trend. In addition, real GDP and bank deposits were non-stationary at constant but stationary at constant with trend in their level forms. Overall, all the variables (dependent, independent, and control parameters) utilized in this study were stationary at first difference for both LLC and IPS. Hence, our choice of the ARDL model is pertinent for the analysis of the study.

**Table 1.** LLC unit root test results.

| Variables | Test statistics | | Probability values | |
|---|---|---|---|---|
| | Constant | Constant + Trend | Constant | Constant + Trend |
| lnBR | -3.411*** | -2.520*** | 0.000 | 0.005 |
| lnΔBR | -10.776*** | -8.184*** | 0.000 | 0.000 |
| lnTEMPTs | 5.836 | 3.234 | 1.000 | 0.999 |
| lnΔTEMPTs | -12.962*** | -10.817*** | 0.000 | 0.000 |
| lnPPTs | 1.991 | 4.803 | 0.976 | 1.000 |
| lnΔPPTs | -11.283*** | -6.740*** | 0.000 | 0.000 |
| lnGHGASs | 52.624 | 138.254 | 1.000 | 1.000 |
| lnΔGHGASs | 10.134*** | -8.840*** | 0.000 | 0.000 |
| lnCCIs | -8.1583*** | -8.263*** | 0.000 | 0.000 |
| lnΔCCIs | -14.424*** | -10.352*** | 0.000 | 0.000 |
| lnBD | -3.567*** | -8.458*** | 0.000 | 0.000 |
| lnΔBD | -17.857*** | -11.840*** | 0.000 | 0.000 |
| lnBCBD | -1.267 | -1.055 | 0.102 | 0.145 |
| lnΔBCBD | -6.850*** | -6.352*** | 0.000 | 0.000 |
| lnINFL | -4.985*** | -5.155*** | 0.000 | 0.000 |
| lnΔINFL | -16.958*** | -13.609*** | 0.000 | 0.000 |
| lnRGDP | -2.640** | -26.629*** | 0.004 | 0.000 |
| lnΔRGDP | -56.837*** | -42.724*** | 0.000 | 0.000 |

**Note:** ***and ** Indicate 1percent and 5percent significance levels.BR is Banking System Resilience, TEMPTs represents Temperature Shock, PPTs signifies Precipitation Shock, GHGASs denotes Greenhouse Gas Shock and CCIs is proxied for Climate Change Index Shock. BD indicates Bank Deposits, BCBD implies Bank Credit-to-Bank Deposits, INFL stands for Inflation and RGDP symbolizes Real Gross Domestic Product. Δ connotes first difference of specified variables and ln indicate natural logarithm.

**Table 2.** IPS unit root test results.

| Variables | Test statistics | | Probability values | |
|---|---|---|---|---|
| | Constant | Constant + Trend | Constant | Constant + Trend |
| lnBR | -5.054*** | -3.063*** | 0.000 | 0.005 |
| lnΔBR | -12.880*** | -9.698*** | 0.000 | 0.0000 |
| lnTEMPTs | -1.451*** | -2.364*** | 0.000 | 0.000 |
| lnΔTEMPTs | -15.215*** | -12.904*** | 0.000 | 0.000 |
| lnPPTs | -11.708*** | -9.250*** | 0.000 | 0.000 |
| lnΔPPTs | -19.546*** | -15.289*** | 0.000 | 0.000 |
| lnGHGASs | 0.8525 | 0.928 | 0.803 | 0.823 |
| lnΔGHGASs | -14.461*** | -12.728*** | 0.000 | 0.000 |
| lnCCIs | -7.958*** | -8.262*** | 0.000 | 0.000 |
| lnΔCCIs | -19.738*** | -16.431*** | 0.000 | 0.000 |
| lnBD | -1.003 | -5.331*** | 0.157 | 0.000 |
| lnΔBD | 14.803*** | 10.742*** | 0.000 | 0.000 |
| lnBCBD | -1.267 | -1.055 | 0.102 | 0.145 |
| lnΔBCBD | -7.101*** | -5.152*** | 0.000 | 0.000 |
| lnINFL | -6.388*** | -5.142*** | 0.000 | 0.000 |
| lnΔINFL | -19.513*** | -16.260*** | 0.000 | 0.000 |
| lnRGDP | -0.321 | -12.775*** | 0.374 | 0.000 |
| lnΔRGDP | -23.304*** | -18.823*** | 0.000 | 0.000 |

**Note:** *** indicate 1 percent significance levels. BR is Banking System Resilience, TEMPTs represents Temperature Shock, PPTs signifies Precipitation Shock, GHGASs denotes Greenhouse Gas Shock and CCIs is proxied for Climate Change Index Shock. BD indicates Ban k Deposit, BCBD implies Bank Credit-to-Bank Deposit, INFL stands for Inflation and RGDP symbolizes Real Gross Domestic Product. Δ connotes first difference of specified variables and ln indicates natural logarithm.

To circumvent specious regression with the aim of attaining a stable long-run equilibrium, we perform a co-integration test. We apply the Kao (1999) co-integration test. The results of the Kao (1999) co-integration test reveal the existence of long-run relationship, given the significance of the p-values in all four models. Table 3 shows the results of the Kao (1999) co-integration test.

**Table 3.** Kao (1999) co-integration test results.

| Model | T-statistics | P-value |
|---|---|---|
| 3 | -2.242** | 0.012 |
| 4 | -2.984*** | 0.000 |
| 5 | -4.333*** | 0.000 |
| 6 | -1.664** | 0.048 |

**Note:** *** and ** indicate the significance level at 1 percent and 5 percent respectively. Model 3 is specified as lnBRlnTEMPTslnBDlnBCBDlnINFLlNGDP, Model 4 as lnBRlnPPTslnBDlnBCBDlnINFLlnGDP, Model 5 is showed as lnBRlnGHGASslnBDlnBCBDlnINFLlnGDP and Model 6 is indicated as lnBRlnCCIslnBDlnBCBDlnINFLlnGDP. Where BR is Banking System Resilience, TEMPTs is Temperature Shock, PPTs is Precipitation Shock, GHGASs is Greenhouse Gas Shock, CCIs is Climate Change Index Shock. BD is Bank Deposits. BCBD denote Bank Credit-to-Bank Deposits. INFL represents Inflation. RGDP connotes Real Gross Domestic Product. ln symbolizes natural logarithm.

### *4.1. Panel ARDL Results*

With the establishment of a long-run relationship according to the Kao (1999) co-integration test, we proceed to test the short-and long-term impact of climate change shocks on banking system resilience in selected Sub-Saharan economies using the pooled mean group (PMG). Motivated by Alagidede, Adu, and Frimpong (2016), the ARDL model unfolds information with regard to concurrent impacts and the speed of adjustments at equilibrium after a shock. The panel ARDL results are presented in Table 4. The displayed Table 4 presents four alternate models. All models contain their respective climate change shock measurement; thus, model 3 has temperature shock as its climate change shock measure, precipitation shock for model 4, greenhouse gas shock for model 5 and 6 has climate change index shock as its climate change shock variable. The results of the respective climate change shock variables employed in the assessment are discrepant in signs as well as statistical significance. For instance, temperature shock and climate change index shock reported a significant positive coefficient in the long-term as well as the short-term coefficient of precipitation shock. That notwithstanding, the signs for both long-term and short-term greenhouse gas shock, as well as the long-term coefficient for precipitation shock were expected. Also, the signs for the error correction terms were expected in all models (3-6), thus negative and significant. Approximately 44.50 percent, 41.73 percent, 54.97 percent, and 54.62 percent of the distortion from the preceding year's shock converge back to the long-term equilibrium in the current year for models 3-6, respectively.

Intuitively, we infer from Table 4 that the long-term impact of temperature shock on banking system resilience is 1.8660. It passed the statistical significance level of 1 percent. This demonstrates that temperature shock will increase banking system resilience by 1.8660 when there is a percentage rise in temperature shock. The positive coefficient of temperature shock indicates that the banking systems in SSAare resilient to temperature shock in the long-term for model 3. We primarily attribute this to the fact that warm and hot temperatures prevail in SSA. We know from agricultural concepts that an auspicious temperature condition is a necessity for good agricultural yields. Therefore, an upsurge in agricultural production increases the aggregate supply in the economic system, which reduces food inflation. Recall on the premise that reduced inflation dwindles the cost of living of various economic agents, hence the ability of borrowers (farmers and suppliers) as well as bank-dependent enterprises to repay their loans and make large deposits at the bank, which in turn decreases the credit risk of banks. Frequently, banks are highly exposed to credit risk in poor weather conditions, as borrowers (farmers and suppliers) will default on their loans. A reduction in credit risk safeguards the quality of bank assets (loans) which provide good returns for banks, thereby increasing their capacity to absorb unexpected downturns. From the foregoing, we posit that temperature, coupled with other exogenous environmental factors, affects assets used as collateral. It causes wear and tear on various collateral assets and depreciates their value. Indeed, high-quality collateral serves as insurance (security) for the banking sector. In the case of default, these assets can be liquidated to offset the bad debt setting banks on their toes, thereby, reducing the non-performing loan ratio of banks.

More so, precipitation negatively impacts banking system resilience in the long term for model 4. The relationship is strongly significant at 1 percent significance level. On average, a percentage increase in precipitation shock will decrease banking system resilience by 0.1083 percent. We deduce that low levels of precipitation affect crop yields and eventually have a detrimental impact on the finances (revenue and income) of farmers and suppliers. Low financial transactions by agriculture agents affect banks' balance sheets via their profitability and bank reserves, making banks insolvent and less resilient to risk exposures. Nonetheless, Stan, Watt, and Sanchez-Azofeifa (2021) explain that the precipitation pattern is perilous to economic reparations as it creates risk that affects infrastructure and financial stability. The negative result demonstrates that banks in SSA are not resilient to precipitation in the long term. In addition, we focus our discourse on model 5 on the emphasis of greenhouse gas shock and banking system resilience linkage in the long term. We conclude that a negative relationship exists between greenhouse gas shock and banking system resilience. As indicated in Table 4, a percentage increase in greenhouse gases will lessen banking system resilience by 0.1365 percent.

Generally, greenhouse gases cause warming that damages efficiency and reduce work output via deleterious heat waves. It has an intricate impact on food systems (food chain), eco-systems, infrastructure, and physical assets, which lowers financial transactions. Additionally, it affects the health of the banking sector with regard to their ability to deal with risk exposures such as carbon-intensive taxes, green bonds, green credits, and other important financial products, making banks less resilient. The finding shows that the banking sectors in SSA are not resilient to greenhouse gas shocks.

On the other hand, the climate change index shock reported a positive and insignificant coefficient. Taking an inferential overview of the outcomes of the control variables we infer that in the long–term, bank deposits reported a negative statistically significant coefficient in models 3 and 5. Nonetheless, for models 4 and 6 a negative coefficient of bank deposit was recorded, but was insignificant. Ceteris paribus, a percentage increase in bank deposits will reduce banking system resilience by 3.3669 percent in model 3 and 0.5631 percent in model 5, respectively. A Bank deposit measures the amount of money (demand deposit) placed in a deposit account. A decrease in bank deposits is very lethal to the operations of the banking sector. Deposits are the fundamental requirement for ensuring the sustainability and resilience of the banking industry in the face of potential shocks. Therefore, the presence of low deposits increases the vulnerability of banks to liquidity risks. Additionally, it diminishes the availability of funds that can be leased for the purpose of lending. Moreover, a reduction in bank deposits lessens bank reserves. Overall, it suppresses banks operations, and banks become vulnerable to shocks. Again, low bank deposits intensify banks vulnerability to shocks. Although SSA's financial system is mainly bank-based, Nyantakyi, Sy, and Kayizzi-Mugerwa (2015) hint that it is perfunctory (shallow financial depth). Intrinsically, the authors argue that bank deposits as a percentage of GDP are low, particularly in West and East African economies. Besides,Nyantakyi et al. (2015) establish that financial penetration is very low in SSA with less population having access to bank accounts. Generally, less financial inclusion.

In explaining the outcome with regards to bank credit-to-bank deposits, we observe from Table 4 that bank credit-to-bank deposits had a negative relationship with banking system resilience in all four models in the long-term. However, it was significant in models 4 and 5. This means that a percentage increase in bank credit-to-bank deposits decreases banking system resilience by 4.8479, and 4.1971 respectively. According to Riadi (2018), bank credit–to-bank deposits is used to gauge banks liquidity with a comparative analysis of total loans to total deposit. Contrarily, the negative and significant coefficients of bank credit-to-bank deposits indicate that the banking sectors in SSA are not fortified. Again, banks have inadequate liquidity to shield against unanticipated shocks. Revolving around macroeconomic control variables, inflation posted both positive and negative correlations in its respective models. Thus, models 3-5 had a significant positive relationship between inflation and banking system resilience. While in model 6 a significant negative relationship was established between the two aforesaid estimates. All else unchanged, an increase in inflation will increase banking system resilience by 0.5204 and 0.1195 percent, respectively, in models 3 and 5. The finding strikes a chord with the results of Apergis and Apergēs (2022), who reported a positive association between inflation and resilience. On the other hand, a percentage increase in inflation will decrease banking system resilience by 0.1590. However, in model 4, the inflation coefficient was insignificant. The credit rationing concept suggests that increased inflation has the effect of displacing both creditworthy borrowers and borrowers with higher credit risk. It is important to acknowledge that creditors assess the creditworthiness and risk level of applicants.

Inflation is commonly used to gauge the stability or instability of the macro economy; thus, higher inflation indicates greater uncertainty. In addition, the higher the uncertainty, the more it affects future projects. Therefore, in the midst of uncertainty, information asymmetry increases, such that when banks are evaluating loan applicants, they are faced with adverse selection problems to differentiate between good borrowers and credit-risky borrowers. Because of the differences between the two types of borrowers, banks increase interest rates. However, those who are good borrowers and have viable investment projects (less risky) will withdraw from the credit market. As such, individuals with risky investments (without a viable project) will borrow more. Therefore, if the banking sector is crowded with a pool of risky borrowers, repayment of the loans will be difficult. This will affect banking performance and expose banks to credit risk, affecting the resilience of the banking system. It is interesting to point out that the impact of inflation on banking system resilience is not robust since it changes signs with different proxies of climate change shocks. That being said, real gross domestic product reported a positive coefficient in all four models in the long-term. Per contra, statistical significance was achieved for models 3,5, and 6. Therefore, a percentage increase in real gross domestic product increases banking system resilience by 0.8241 percent, 0.4347 percent, and 0.4184 percent respectively. Plausibly, as average income in the economy increases, the purchasing power of economic agents (households, firms) increases as does the demand for goods and services. On that note, economic agents are motivated to increase their investment expenditures. Correspondingly, economic agents will be in a good state to repay their loan which reduces banks credit risk exposures as well as non-performing loans (NPLs). This positively affects banks resilience. More so, the result is in tandem with the outcome of Apergis and Apergēs (2022), who found GDP to be positively related to resilience.

With reference to the short-term impact of climate change shocks on banking system resilience, it is observed from Table 4 that temperature shocks have a negative and insignificant relationship with banking system resilience. Needless to say, a significant positive nexus was observed between precipitation shock and banking system resilience.

We conclude that a percentage increase in precipitation shock will increase banking system resilience by 0.1715 percent. Seemingly, SSA is mostly an agrarian continent, with its people heavily engaged in agriculture and its allied activities. Hence, good rainfall increases crop productivity and its food chain mechanism (transmission). This increases the income levels of agriculture agents, which enhances economic and financial transactions.

As a result, it increases bank deposits and performance, which makes banks resilient to shocks. On the flip side of the coin, both greenhouse gas and climate change index shocks had a negative and insignificant relationship with banking system resilience in the short-term. For control variables, bank deposits reported an insignificant positive relationship with banking system resilience for models 3 and 4. In addition, a negative, insignificant association was recorded between bank deposits and banking system resilience in the short-term for models 5 and 6.

A crucial overview of bank credit-to-bank deposits reveals that a positive coefficient was reported for all four models. However, only model 3 had a significant coefficient. For inflation, a negative, insignificant relationship was observed for model 3. On the other hand, insignificant positive coefficients were evident for models 4 and 5. Further, a significant positive nexus was reported for inflation and banking system resilience in model 6.

Thus, an increase in inflation will increase banking system resilience by 0.2339, all else unchanged. Concerning the short-term impact of real GDP on banking system resilience, we establish that all four models had a positive coefficient. Conversely, it is insignificant for model 3 and significant for models 4-6. On average, a percentage increase in real GDP will increase banking system resilience by 0.8570, 1.0464, and 0.7218, respectively.

**Table 4.** Long-term and short-term panel ARDL results.

| **Models** | | **Model 3** | **Model 4** | | **Model 5** | | **Model 6** | |
|---|---|---|---|---|---|---|---|---|
| **Long-term impact** | | | | | | | | |
| **Variables** | **Coefficient** | **Std. error** | **Coefficient** | **Std. error** | **Coefficient** | **Std. error** | **Coefficient** | **Std. error** |
| lnTEMPTs | 1.866 | 0.229<br>(0.000)*** | - | - | - | - | - | - |
| lnPPTs | - | - | -0.108 | 0.044<br>(0.016)** | - | - | - | - |
| lnGHGASs | - | - | - | - | -0.136 | 0.038<br>(0.000)*** | - | - |
| lnCCIs | - | - | - | - | - | - | 0.108 | 0.136<br>(0.427) |
| lnBD | -3.366 | 0.252<br>(0.000)*** | -0.085 | 0.195<br>(0.662) | -0.563 | 0.203<br>(0.006)*** | 0.007 | 0.202<br>(0.970) |
| lnBCBD | -0.101 | 0.279<br>(0.717) | -4.847 | 0.225<br>(0.000)*** | -4.197 | 0.204<br>(0.000)*** | -0.432 | 0.267<br>(0.107) |
| lnINFL | 0.5204 | 0.052<br>(0.000)*** | 0.005 | 0.065<br>(0.937) | 0.119 | 0.063<br>(0.060)* | -0.159 | 0.091<br>(0.082)* |
| lnRGDP | 0.824 | 0.113<br>(0.000)*** | 0.036 | 0.099<br>(0.718) | 0.434 | 0.119<br>(0.000)*** | 0.418 | 0.096<br>(0.000)*** |
| Short-term impact | | | | | | | | |
| lnΔTEMPTs | -2.115 | 1.348<br>(0.118) | - | - | - | - | - | - |
| lnΔPPTs | | - | 0.171 | 0.096<br>(0.075)* | - | - | - | - |
| lnΔGHGASs | - | - | - | - | -0.404 | 0.437<br>(0.355) | - | - |
| lnΔCCI | - | - | - | - | - | | -0.143 | 0.403<br>(0.722) |
| lnΔlnBD | 1.755 | 1.547<br>(0.2576) | 0.217 | 0.980<br>(0.8246) | -0.541 | 1.100<br>(0.623) | -0.178 | 1.254<br>(0.887) |
| lnΔBCBD | 2.760 | 0.922<br>(0.003)*** | 0.973 | 0.890<br>(0.275) | 1.011 | 0.901<br>(0.263) | 0.915 | 0.688<br>(0.184) |
| lnΔINFL | -0.263 | 0.167<br>(0.115) | 0.104 | 0.099<br>(0.292) | 0.114 | 0.082<br>(0.168) | 0.233 | 0.079<br>(0.003)*** |
| lnΔRGDP | 1.004 | 0.668<br>(0.134) | 0.857 | 0.462<br>(0.064)* | 1.046 | 0.560<br>(0.063)* | 0.721 | 0.345<br>(0.037)** |
| ECT | -0.445 | 0.106<br>(0.000)*** | -0.417 | 0.104<br>(0.001)*** | -0.549 | 0.095<br>(0.000)*** | -0.546 | 0.077<br>(0.000)*** |
| C | -4.634 | 1.363<br>(0.000)*** | 10.301 | 2.536<br>(0.000)*** | 6.138 | 1.087<br>(0.000)*** | -4.548 | 0.712<br>(0.000)*** |

**Note:** ***, ** and * indicate 1 percent, 5 percent and 10 percent significance levels. BR is Banking System Resilience, TEMPTs represents Temperature Shock, PPTs signifies Precipitation Shock, GHGASs denotes Greenhouse Gas Shock and CCIs is proxied for Climate Change Index Shock. BD indicates Bank Deposits, BCBD implies Bank Credit-to-Bank Deposits, INFL stands for Inflation and RGDP symbolizes Real Gross Domestic Product. $\Delta$ connotes first difference of specified variables and ln indicates natural logarithm.

## 5. Conclusion

For some time now, climate change has been seen as a scourge that poses discrete threats. Copious scholars have voiced their differences on the impact of climate change on various sectors of the economy. Until now, the impact of climate change on the general economy and sectors such as agriculture, tourism, and animal husbandry has been well documented in empirical literature, but little can be said for the banking sector among the international communities and some developing economies. More importantly, in a keynote address in 2015 on “Breaking the tragedy of the horizon-climate change and financial stability”, Mark Carney, the former Bank of England governor, posits that the next global financial crunch will be caused by climate change. Since then, climate-related risks to the financial sector have received enormous attention in the academic community. Despite the concomitant discourse about the impact of climate change on financial sectors, research in the Sub-Saharan economies is still in its infancy. It is believed that SSA economies financial sectors are mainly bank-based, and as such, their preparedness to shocks such as climate change is unknown. On that note, we forecast climate change uncertainties and their upshots on the banking systems in selected SSA economies using the GARCH (1,1) model to obtain the volatility series of the respective climate change variables. Further, the panel ARDL is employed to disseminate both the long-term and short-term impact of the obtained conditional variances of climate change shocks on banking system resilience within a time frame from 1996-2017.

In particular, we find that the long-term banking systems in SSA are resilient to temperature shock. On the other hand, we concur that banking systems in SSA are not resilient to precipitation and greenhouse gas shocks in the long-term. Turning our discourse on the short-term impact of climate change on the banking system resilience relation, we conclude that banking systems in SSA are resilient to only precipitation shock.

In this regard, we recommend that banking systems in the SSA vigorously conduct stress testing on climate-related financial risks. It is worth noting that stress testing is an important procedure to enumerate possible systemic shocks that will impact the resilience of the banking system. Climate stress-testing techniques have the tendency to (1) detect the path-change of climate-related financial risks in the short-term, (2) reveal the physical property losses via physical risks and delicate transition policies, (3) disclose the interaction between physical risks and transition risks, and (4) determine the augmentation impact of the response loop between physical risks and transition risks. Also, beyond the standard climate change stress testing, banks can model the complexities of climate-related financial risks and determine their implications for their resilience. More importantly, banks in SSA should design forward-looking strategies and climate change risk management procedures in the wake of climate change events. Further, monetary authorities in the SSA region should undertake proper supervision as well as collaborate with internal and external agencies leading the climate change implementation to manage climate-related financial risks.

Additionally, the study contributed to the climate change-banking system resilience association, which is vastly understudied in SSA. However, for data limitations, we only used five parameters to create an index for banking system resilience. We suggest that future studies should extend the parameters for banking system resilience, such as non-performing loans, bank asset size, bank concentration, monetary policy actions, etc., as well as the countries utilized in this study.

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## Appendix

**Appendix 1.** List of countries.

| | |
|---|---|
| Angola | Namibia |
| Burkina Faso | Rwanda |
| DR. Congo | Sudan |
| Gabon | Zambia |
| Kenya | Botswana |
| Malawi | Eswatini |
| Mozambique | Ghana |
| Nigeria | Madagascar |
| South Africa | Mauritius |
| Togo | Niger |
| Benin | Senegal |
| Cote D'Ivoire | Tanzania |
| The Gambia | Cameroon |
| Lesotho | Burundi |
| Mali | |