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Asymmetric impact of climate change on banking system stability in selected sub-Saharan economies

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ABSTRACT

This study is an empirical examination of the asymmetric impact of climate change on banking system stability in selected sub-Saharan economies. The study leverages a quantitative research approach through a panel non-linear ARDL framework and data from 29 selected economies, which spans 1996-2017. Findings from the study reveal that in the long term, partial sums of temperature have an insignificant relationship with banking system stability. Further, partial sums of precipitation are negatively related to banking system stability in the long term. The finding indicates that both positive and negative precipitation do harm banking system stability in the selected sub-Saharan economies. Moreover, we find that partial sums of greenhouse gas emissions had an insignificant relationship with banking system stability. In addition, we conclude that greenhouse gases (positive and negative) do not impair banking system stability in selected sub-Saharan economies in the long term. We surmise from the findings that both positive and negative climate change indexes are harmful to banking system stability. On the short-term asymmetric impact, we discover that partial sums of temperature, precipitation, and climate change index do not harm banking system stability. However, negative greenhouse gas emissions are pernicious to the banking system's stability in the short term. Conversely, positive greenhouse gas levels were statistically insignificant. The study recommends that central banks and monetary authorities in Sub-Saharan Africa design green banking policies to push the climate change agenda in the banking sector.

Contribution/Originality: This study serves as the foundation to understand climate change's impact on banking system stability in Sub-Saharan Africa from an asymmetric framework.

1. INTRODUCTION

Climate change has become a global concern in present times. Fang, Yin, and Wu (2016) expound that climate change is one of the sustainability challenges facing the global economy. That notwithstanding, climate change impacts on ecosystems are catastrophic (Zhang, Zhang, & Fang, 2023). However, Zhang, Chang, and Xuan (2022) claim that climate change has a detrimental impact on the environment, production, and life in the world. It is imperative to highlight that effects of climate change are bad for the general economic system. Against this background, Sun, Yang, Huang, and Zou (2020) declare that risks emanating from climate change affect banking systems via direct and indirect streams. Importantly, the effects of climate change can lead to diversification in the banking system. That said, climate change can amplify its impact and disrupt the whole banking system's operations. It is worth mentioning that the banking sector is the front liner of every business across the globe, and any detrimental impact on the banking system will halt business operations. Climate change is unpredicted, but its effects occur in both the short- and long-term. The banking sector provides financial services such as deposit-taking, loan provision, payment system's and investments, amongst others. In addition, the banking system is a functional unit that enables transaction of money between firms, individuals, and other financial institutions. Climate change is strongly accredited as having sizable consequences on banks (Khurshid, Fiaz, Khurshid, & Ali, 2022). On that account, climate change's impact on the banking system could increase insurance costs, distort policies and regulations, and lead to litigation. Essentially, the challenges posed by climate change on the banking sectors are worrisome, and it requires stringent adaptation as well as mitigation procedures. Le, Tran, and Mishra (2023) suggest that policymakers concur that climate change poses a serious threat to the safety and stability of financial systems. Climate change poses numerous risks, such as credit risk, operational risk, liquidity risk, market risk, legal risk, and reputational risk, amongst others, that impact banks' operations, which ultimately affect banking system stability. Carney (2015) suggests that climate change risks are sources of financial risk. Therefore, it is worth emphasizing that climate change does not form any new risk but rather accentuates existing risks such as operational risk, market risk, and credit risk or risk in line with insurance underwriters (Scott, van Huizen, & Jung, 2017). Further, a 2018 report by the Bank of England highlights that climate change is no longer a corporate social responsibility activity, with most banks viewing it as any other important financial risk. The Economist Intelligence Unit, as cited in Javadi and Masum (2021) states that the Value at Risk (VAR) of manageable assets with regards to climate change impact is USD 4.2 trillion.

The authors argue that it is impossible to hedge climate change risk, and banks are increasingly focusing on environmental sensitivity (Fard, Javadi, & Kim, 2020). Globally, the impact of climate change is evident in different geographical settings with financial cushions to combat its ramifications. Climate change has recently reorganized the banking system as one of its vulnerable sectors. This is a significant issue, as banking system plays a crucial role in fostering economic growth and development in every nation. Sub-Saharan Africa, in particular, is considered as one of the regions liable to climate change shocks (Africa Development Bank, 2019). As a result, climate change could have a deleterious effect on the banking system, yet we know very little about the asymmetric impact of climate change on banking system stability. To date, no empirical evidence can be traced to sub-Saharan region in the context of the asymmetric impact assessment of climate change-banking system stability nexus. Therefore, the study aims to investigate the asymmetric impact of climate change and banking system stability relationships by decomposing climate change variables into positive and negative partial sums. Omoke, Opuala-Charles, and Nwani (2020) mention that an awareness of the asymmetric impact is based on the premise that the effect of a positive change can differ from that of a negative change in absolute terms.

Indeed, it is believed that the constant change in climatic conditions in Sub-Saharan Africa (SSA) has become perilous to the banking system. The research area is crucial in light of the fact that majority of the financial system in SSA is mainly bank-based. The paper is organized thus: Section 2 presents the overview of climate change risk and banking system activities.

Section 3 presents the literature review. Section 4 contains the methodology. Section 5 discusses the findings. Section 6 presents the conclusion. The penultimate section presents the recommendation and policy implications. The last section of the paper presents the limitations and direction of future research.

2. CLIMATE CHANGE RISK AND BANKING SYSTEM ACTIVITIES

According to the Bank for International Settlements (2021) monetary authorities have devoted enormous attention to quantifying the effects of climate change on the banking system. Climate change has a detrimental impact on asset quality. In essence, climate change risk diminishes borrower's wealth with a destruction to physical assets, which affects banks capacity to recover the loans (Nie, Regelink, & Wang, 2023). Further, Nie et al. (2023) claim that climate change risk affects capital adequacy, net interest margin, liquidity-to-deposit ratio, as well as credit to the private sector. Significantly, risk originating from climate change can intensify risks such as credit risk, operational risk, liquidity risk, and technology risk, amongst others. U-Din, Nazir, and Shahzad (2023) explicate that climate change enables banks to lower their risk level and improve stability as a result of pro-active risk management procedures. De Bandt, Jacolin, and Thibault (2021) show that credit risk from climate change comprises risk associated with loan default as well as bond exposures. Further, market risk from climate exposures is centered on equity and non-bond exposures. The authors argue that credit risk is important to banks, and they can reshuffle loan portfolios before climate-related risks manifest. In the event of climate change disasters, Correa, He, Herpfer, and Lel (2022) argue that spreads on loans increase, and that impacts the profits of the repayment of commercial loans (Kousky, Palim, & Pan, 2020). Nonetheless, some authors contend that climate change risk affects agricultural loans. For instance, Kaur Brar, Kornprobst, Braun, Davison, and Hare (2021) establish that agriculture is important in climate change studies. Overall, climate change affects the lending capacity of banks. For market risk, climate change could affect, commodity prices, exchange rates, stock prices, and interest rates with spillover effects on the banking sector (De Bandt et al., 2021). The Allianz Global Investors (2024) mention that the banking sector is highly exposed to climate change repercussions through its financial activities, which are far more than its operations, and has a potential gain via opportunities in the transition processes. Mckinsey & Company (2020) assert that climate change presents both opportunities and challenges for the banking industry. Moreover, the National Whistleblower Centre (2024) website reports that banks can contribute to climate change crisis when they profit from money laundering and illicit finance. With regards to SSA banking system activities and climate change repercussions, Emmanuel Amo-Bediako, Takawira, and Choga (2023) argue that the impact of any exogenous disturbance on SSA banking system is of importance. Besides, Amo-Bediako, Takawira, and Choga (2024) claim that climate change repercussions are lethal to financial assets.

3. LITERATURE REVIEW

Prior to this present study, no specific empirical evidence has been documented regarding the asymmetric relationship between the stability of the banking system and climate change except a related study on the impact between climate change and financial stability in China. In that study, Liu, Sun, and Tang (2021) find that both positive and negative climate change shocks are pernicious to financial stability. The study used monthly data from 2002-2018 and applied the non-linear Autoregressive Distributed Lag (NARDL) through a time series framework to investigate the non-linear asymmetric impact on China's financial stability.

3.1. Conceptual Framework

Figure 1 depicts the conceptual framework in accordance with the objective of the paper. According to the conceptual framework displayed, climate change variables are independent variables. Climate change variables are decomposed into partial sums (+/-).

Drawing upon existing literature, the study proposes the following hypothesis:

H_1: Climate change has a significant asymmetric impact on banking system stability in selected sub-Saharan economies.

In light of this, the study discusses the financial instability hypothesis postulated by Minsky (1977) as a guiding theory and presented in Section 3.2.

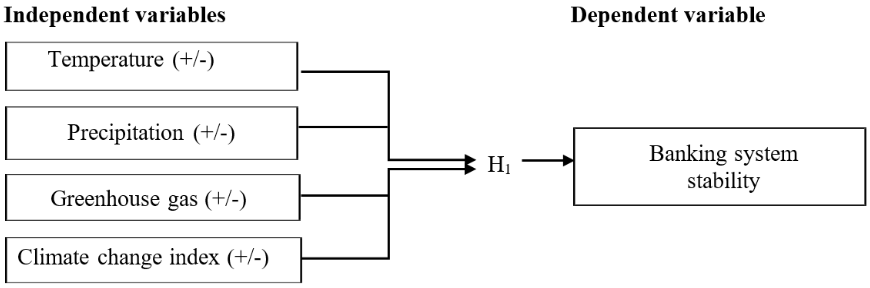

Figure 1. Conceptual framework of asymmetric impact of climate change on banking system stability.

3.2. Financial Instability Hypothesis

Proposed by renowned economist Minsky (1977) the financial instability hypothesis (FIH) is an economic theory that suggests that financial markets and institutions can create instability in the general economy. Maphosa (2020) defines financial instability as the outbreak of problems in the financial system. The author argues that Minsky (1977) model occurs when shocks to the financial system interfere with information outlay, undercutting financial system performance. Sandoval (2017) argues that Minsky (1977) financial instability hypothesis comprises two concepts: empirical and theoretical concepts. He suggests that the empirical perspective resonates with theoretical framework of the historical episodes. On the theoretical forefront, Sandoval (2017) highlights that Minsky (1977) hypothesis starts from the characterization of the economy as a sophisticated financial system. Rozmainsky, Kovezina, and Klimenko (2022) allude to Minsky (1977) hypothesis that crises are caused by external shocks. Moreover, the authors refer to Minsky (1977) financial instability hypothesis as financial fragility hypothesis (FFH). Kregel (2018), as referenced in Marshall (2021) established that:

For Minsky, financial fragility is a never-ending story, it cannot be eliminated or avoided, however, more understanding can be developed from it.

Maphosa (2020) also refers to financial fragility as the exposures of the financial system to unexpected shocks within the financial system. According to King (2013) the FIH abridged the reasons through which the economic system is vulnerable to financial crises. In his thesis, *'Shadow banking, financial stability, and economic performance'*, Zhou (2019) wrote that Minsky (1977) was contentious of the neoclassical explanation of Keynes (1937) General Theory of Employment, interest and Money; rather, he argued in favour of financial turmoil, which he believes is a driving force of the General Theory. It is contended by Zhou (2019) that the theory is based on industrial firms, households, and governments. Financial markets are accessible to all agents, and monetary claims are traded on financial markets (Zhou, 2019). It is the view of Perepelkina and Rozmainsky (2023) that the FIH was a substitute for the standard neoclassical theory with an interpretation based on Keynes (1937) General Theory of Employment, Interest, and Money. Further, Minsky (1992) explains that FIH is construal of Keynes (1937) General Theory of Employment, Interest, and Money. More importantly, the attraction of FIH began after the great economic recession. According to Perepelkina and Rozmainsky (2023) one of the earliest empirical applications of the FIH were Mulligan (2013) and Mulligan, Lirely, and Coffee (2014). A study by Reis and Vasconcelos (2016) uncovers Minsky (1977) and Minsky (1992) financial instability hypothesis as a powerful theory to explain financial crises. Based on this description, the authors explicate that the economy has endogenous mechanisms that render the system to reverse the prevailing economic situation in the event of increasingly less relevant shocks. Explicitly, a magnitude of shock could lead to financial system collapse (Reis & Vasconcelos, 2016).

In his proposition, Minsky (1977) argues that a firm's asset values measure its investment portfolio and determine its debt obligation. It is crucial to emphasize the theory's foundation rests on the classification of the economic system as a capitalist economy, in conjunction with intricate financial systems. According to Minsky (1977) financial systems and their interrelations are paramount to capitalist economy which unavoidably leads to excessive fluctuations in the economy. Against this backdrop, the financial instability hypothesis characterization comes with the support of erudite financial systems and capital assets, which are costly. From Minsky (1992) purview, the financial instability hypothesis integrates profit determination as suggested by Kalecki (2013). In this regard, Minsky (1992) suggests that banks are considered profit-making firms and would only maximize profits by financing activities.

Indeed, the FIH has two theorems, first. Minsky (1977) quotes that the economy is bonded by two financial regimes under which stability is achieved at one end and another with a financing regime with instability. Second, in a period of protracted wealth, the economy transcends from a stable financial relationship to one that makes it unstable. There has been criticism of the financial instability hypothesis. Marshall (2021) shows that a cursory look at the theory casts doubt on the assertion that stability creates instability, and it does not specifically account for the period of the creation. Keen (2020) argues that Minsky (1977) abandoned the idea of the mathematical implication of his hypothesis. He contends that Minsky (1977) financial instability hypothesis is derived from sound macro-foundations. Further, the author suggests that the theory is a complex one; therefore, numerous scholars have contributed their quota in building a mathematical model for the theory's representation, which Minsky corroborated in some of them; see, for example, Gatti, Gallegati, and Minsky (1996).

The financial instability hypothesis is one of the rarest concepts in the history of economics (Keen, 2020). Nonetheless, Reis and Vasconcelos (2016) argue that Minsky (1977) financial instability hypothesis has a foundation of variations in the fragility of the economy. Despite this, fragility rises from a low level and imperceptible erosion of bank safety (Reis & Vasconcelos, 2016). Miller (2018) states that Minsky (1977) legacy is two-folded, comprising the real market analysis and financial market analysis, which should be carried out together and not in isolation.

Lavoie (2016) shares the view that Minsky (1977) perception of the financial system is termed the financial instability hypothesis. Torres Filho, Martins, and Miaguti (2019) argue that not only does the financial instability function at the aggregate level, but it is pertinent at a disaggregate level (microeconomic level) and distorts financial soundness. Torres Filho et al. (2019) state that Minsky (1977) financial instability hypothesis is fervent to economies operating under both stable and unstable financial regimes. Moreover, the authors indicate that under FIH, an economy can transfigure from financial relations that account for a stable financial system to financial relations that contribute to an unstable financial system (Minsky, 1992).

The financial instability hypothesis, as opined by Minsky (1977) is a framework that does not depend only on exogenous shocks. Although not wholly dependent on exogenous shocks climate change is considered an exogenous shock; as such, the theory is applied in this study. Further, the banking system is part of the economic sector that generates profits; hence, repression from climate change will intensify financial fragility. Furthermore, the manifestation of financial fragility can manifest itself quickly in deteriorating the value of collaterals when periodic sessions of stability are long-lived (Torres Filho et al., 2019). Therefore, the higher the financial fragility in an economic system, the higher the effect of unexpected fluctuations (Torres Filho et al., 2019).

4. METHODOLOGY

4.1. Data

The study employs 29 selected sub-Saharan economies for the period 1996-2017 (see Appendix 1 for the list of countries selected). The choice of the selected economies was based on the availability of data. More importantly, the study utilized four climate change variables, which include temperature, precipitation, greenhouse gas emissions, and climate change index. It is worth noting that data for temperature and precipitation were sourced from World Bank Climate Change Knowledge Portal. In addition, greenhouse gas emissions data was obtained from Climate Watch online database. A climate change index was created from the three aforementioned climate change variables using the principal component analysis (PCA). Further, we use bank Z-score as a proxy for banking system stability, and the data was taken from the World Bank Global Finance Development Database. It should be noted that data for bank Z-score is the national aggregate data. Also, the study controlled for variables such as net interest margin, money supply, bank concentration, and regulatory quality. Table 1 shows the variables utilized in the study, notations, the expected signs of the variables, and the source of the data employed in the study.

Table 1. Description of variables.

Variables	Notation	Apriori expectation	Source
Banking system stability	BS	Depended.	Global finance development
Temperature	TEMPT	-	Climate change knowledge portal
Precipitation	PPT	-	Climate change knowledge portal
Greenhouse gas emissions	GHGAS	-	Climate watch
Climate change index	CCI	-	Principal component analysis
Net interest margin	NIM	+	Global finance development
Money supply	MS	+	World development indicators
Bank concentration	BC	+	Global finance development
Regulatory quality	RQ	+	World governance indicators

4.2. Model Strategy

In line with the study's objective, we utilize the panel non-linear autoregressive distributed lag (NARDL) model in our regression models. It is worth mentioning that this study serves as a foundation to unveil the asymmetric impact of climate change on banking system stability using the non-linear autoregressive distributed lag (NARDL) in a panel data framework. Anderl and Caporale (2022) hint that there is no prescribed approach to test the existence of non-linearities prior to estimating the model; however, parameter symmetry can be tested after the estimation has been conducted. Postulated by Shin, Yu, and Greenwood-Nimmo (2014) NARDL is an asymmetric model where the explanatory variable is disintegrated into both positive and negative partial sums to examine the long- and short-term transmission effects on the regressor. The panel NARDL model helps in estimating the long- and short-run association between variables that is characterized by asymmetries (Anderl & Caporale, 2022; Arize, Malindretos, & Igwe, 2017).

The econometric model is specified as:

$$BS_{it} = f\,(CLIMATE\ CHANGE, CONT)_{it} \qquad (1)$$

In model 1, *BS* denotes banking system stability. *CLIMATE CHANGE* represents specific climate change variable(s) that is incorporated in the regression model. They are temperature (TEMPT), precipitation (PPT), greenhouse gas emissions (GHG), as well as an index created for climate change (CCI). More so, $CONT_{it}$ is a vector of control variables that consist of bank-specific factors such as Net Interest Margin (NIM) and Bank Concentration (BC). Also, the control variables include macroeconomic factors such as money supply (MS). In addition, governance (institutional) variable such as regulatory quality (RQ) is included in the model as a control variable. Therefore, the following econometric models are specified to achieve the research objective. On that account variables are log transformed and written as:

$$ln\,BS_{it} = \psi_{it} + \alpha_1\, ln\,TEMPT_{it} + \alpha_2 CONT_{it} + \mu_{it} \qquad (2)$$

$$ln\,BS_{it} = \phi_{it} + \varphi_1\, ln\,PPT_{it} + \varphi_2 CONT_{it} + \mu_{it} \qquad (3)$$

$$ln\,BS_{it} = \delta_{it} + \varpi_1\, ln\,GHG_{it} + \varpi_2 CONT_{it} + \mu_{it} \qquad (4)$$

$$ln\,BS_{it} = \gamma_{it} + \beta_1\, ln\,CCI_{it} + \beta_2 CONT_{it} + \mu_{it} \qquad (5)$$

Where ψ_{it},ϕ_{it},δ_{it},γ_{it} are the respective intercepts for model 2 to 5. α_1,α_2 are the coefficients for model 2. Further, φ_1,φ_2 are the coefficients for model 3. Also, ϖ_1,ϖ_2 and β_1,$\beta_2$are coefficients for models 4 and 5 respectively.

4.3. Panel NARDL

The panel NARDL is represented as,

$$\gamma_{it} = \sum_{i=1}^{p} \varphi_k \Delta\chi_{it-i} + \sum_{k}^{q} (\delta_k^+\, \chi_{it-k}^+ + \delta_k^- \chi_{it-k}^-) + \varepsilon_{it} \qquad (6)$$

Where χ_{it} denotes $\kappa x1$ vector of multiple explanatory variables that is defined as $\chi_{it} = \chi_0 + \chi_{it}^{+} + \chi_{it}^{-}$. φ_k represent the autoregressive variable whiles δ_k^{+} and δ_k^{-} symbolizes the positive and negative distributed lag respectively.

The error correction in the Panel ARDL model is specified as;

$$\Delta\gamma_{it} = \mu + \rho ecm_{it} + \theta\Delta\gamma_{it-1} + \sum_{k=1}^{p}(\varphi_k^{+'}\Delta\chi_{it-k}^{+} + \varphi_k^{-}\Delta\chi_{it-k}^{-'}) + \sum_{k=1}^{p}(\delta_k^{+'}\Delta\chi_{it-k}^{+} + \delta_k^{-}\Delta\chi_{it-k}^{-'}) + \varepsilon_{it} \quad (7)$$

Specifically, in this study, we first decompose the explanatory variables as:

$$ln\,T\,EMPT_{it} = ln\,T\,EMPT_0 + ln\,T\,EMPT_{it}^{+} + ln\,T\,EMPT_{it}^{-} \quad (8)$$

$$ln\,P\,PT_{it} = ln\,P\,PT_0 + ln\,P\,PT_{it}^{+} + ln\,P\,PT_{it}^{-} \quad (9)$$

$$ln\,G\,HGAS_{it} = ln\,G\,HGAS_0 + ln\,G\,HGAS_{it}^{+} + ln\,G\,HGAS_{it}^{-} \quad (10)$$

$$ln\,C\,CI_{it} = ln\,C\,CI_0 + ln\,C\,CI_{it}^{+} + ln\,C\,CI_{it}^{-} \quad (11)$$

Where $ln\,T\,EMPT_{it}^{+}$ and $ln\,T\,EMPT_{it}^{-}$, $ln\,P\,PT_{it}^{+}$ and $ln\,P\,PT_{it}^{-}$, $ln\,G\,HGAS_{it}^{+}$ and $ln\,G\,HG_{it}^{-}$, $ln\,C\,CI_{it}^{+}$ and $ln\,C\,CI_{it}^{-}$ denotes the partial sum process of positive and negative variations in temperature, precipitation, greenhouse gas emissions, and climate change index. The specific forms are expressed below:

$$ln\,T\,EMPT_{it}^{+} = \sum_{k=1}^{t} ln\,T\,EMPT_k^{+} = \sum_{k=1}^{t} max(\Delta\,ln\,T\,EMPT_k^{+}, 0) \quad (12)$$

$$ln\,T\,EMPT_{it}^{-} = \sum_{k=1}^{t} ln\,T\,EMPT_k^{-} = \sum_{k=1}^{t} max(\Delta\,ln\,T\,EMPT_k^{-}, 0) \quad (13)$$

$$ln\,P\,PT_{it}^{+} = \sum_{k=1}^{t} ln\,P\,PT_k^{+} = \sum_{k=1}^{t} max(\Delta\,ln\,P\,PT_k^{+}, 0) \quad (14)$$

$$ln\,P\,PT_{it}^{-} = \sum_{k=1}^{t} ln\,P\,PT_k^{-} = \sum_{k=1}^{t} max(\Delta\,ln\,P\,PT_k^{-}, 0) \quad (15)$$

$$ln\,G\,HGAS_{it}^{+} = \sum_{k=1}^{t} ln\,G\,HGAS_k^{+} = \sum_{k=1}^{t} max(\Delta\,ln\,G\,HGAS_k^{+}, 0) \quad (16)$$

$$ln\,G\,HGAS_{it}^{-} = \sum_{k=1}^{t} ln\,G\,HGAS_k^{-} = \sum_{k=1}^{t} max(\Delta\,ln\,G\,HGAS_k^{-}, 0) \quad (17)$$

$$ln\,C\,CI_{it}^{+} = \sum_{k=1}^{t} ln\,C\,CI_k^{+} = \sum_{k=1}^{t} max(\Delta\,ln\,C\,CI_k^{+}, 0) \quad (18)$$

$$ln\,C\,CI_{it}^{-} = \sum_{k=1}^{t} ln\,C\,CI_k^{-} = \sum_{k=1}^{t} max(\Delta\,ln\,C\,CI_k^{-}, 0) \quad (19)$$

To consider the long-term asymmetry between variables, below are equations specified:

$$ln\,B\,S_{it} = \beta^{+}\,ln\,T\,EMPT_{it}^{+} + \beta^{-}\,ln\,T\,EMPT_{it}^{-} + \varepsilon_{it} \quad (20)$$

$$ln\,B\,S_{it} = \beta^{+}\,ln\,P\,PT_{it}^{+} + \beta^{-}\,ln\,P\,PT_{it}^{-} + \varepsilon_{it} \quad (21)$$

$$ln\,B\,S_{it} = \beta^{+}\,ln\,G\,HGAS_{it}^{+} + \beta^{-}\,ln\,G\,HGAS_{it}^{-} + \varepsilon_{it} \quad (22)$$

$$ln\,B\,S_{it} = \beta^{+}\,ln\,C\,CI_{it}^{+} + \beta^{-}\,ln\,C\,CI_{it}^{-} + \varepsilon_{it} \quad (23)$$

Where β^{+} denotes the long-term transmission effect of increasing temperature, precipitation, greenhouse gas, and climate change index on banking system stability. β^{-} represent the long-term transmission effect of decreasing temperature anomalies, rainfall, greenhouse gas, and climate change index.

Based on the above decomposition, the specific form of the panel NARDL can be deduced as,

$$\Delta\,ln\,B\,S_{it} = \varphi + \rho BS_{it-1} + \delta^{+}\,ln\,T\,EMPT_{it-1}^{+} + \delta^{-}\,ln\,T\,EMPT_{it-1}^{-} + \sum_{k=1}^{p-1}\vartheta_k\Delta\,ln\,B\,S_{it-1} + \sum_{k=0}^{q-1}(\pi_k^{+}\,\Delta\,ln\,T\,EMPT_{it-k}^{+} + \pi_k^{-}\Delta\,ln\,T\,EMPT_{it-k}^{-}) + \varepsilon_{it} \quad (24)$$

$$\Delta\,ln\,B\,S_{it} = \theta + \rho BS_{it-1} + \beta^{+}\,ln\,P\,PT_{it-1}^{+} + \beta^{-}\,ln\,P\,PT_{it-1}^{-} + \sum_{k=1}^{p-1}\vartheta_k\Delta\,ln\,B\,S_{it-1} + \sum_{k=0}^{q-1}(\phi_k^{+}\,\Delta\,ln\,P\,PT_{it-k}^{+} + \phi_k^{-}\Delta\,ln\,P\,PT_{it-k}^{-}) + \varepsilon_{it} \quad (25)$$

$$\Delta\,ln\,B\,S_{it} = \phi + \rho BS_{it-1} + \lambda^{+}\,ln\,G\,HGAS_{it-1}^{+} + \lambda^{-}\,ln\,G\,HGAS_{it-1}^{-} + \sum_{k=1}^{q-1}\pi_k\Delta\,ln\,B\,S_{it-1} + \sum_{k=0}^{p-1}(\kappa_k^{+}\,\Delta\,ln\,G\,HGAS_{it-k}^{+} + \kappa_k^{-}\Delta\,ln\,G\,HGAS_{it-k}^{-}) + \varepsilon_{it} \quad (26)$$

$$\Delta\,ln\,B\,S_{it} = \sigma + \rho BS_{it-1} + \alpha^{+}\,ln\,C\,CI_{it-1}^{+} + \alpha^{-}\,ln\,C\,CI_{it-1}^{-} + \sum_{k=1}^{q-1}\vartheta_k\Delta\,ln\,B\,S_{it-1} + \sum_{k=0}^{p-1}(\omega_k^{+}\,\Delta\,ln\,C\,CI_{it-k}^{+} + \omega_k^{-}\Delta\,ln\,C\,CI_{it-k}^{-}) + \varepsilon_{it} \quad (27)$$

Where $ln\,B\,S$ denotes banking system stability and $ln\,T\,EMPT$, $ln\,P\,PT$, $ln\,G\,HG$, $ln\,C\,CI$ represent climate change variables, thus, temperature, precipitation, greenhouse gases and climate change index, respectively. Δ signifies the first-order difference. ε is the residual term. p is the maximum lag order of the regressor and q is the maximum lag of the independent variable.

$$\Delta\,ln\,B\,S_{it} = \rho\xi_{it-1} + \sum_{k=1}^{p-1}\pi_k\Delta\,ln\,B\,S_{it-k} + \sum_{k=0}^{q-1}(\delta_k^{+}\,\Delta\,ln\,T\,EMPT_{it-k}^{+} + \delta_k^{-}\Delta\,ln\,T\,EMPT_{it-k}^{-}) + \varepsilon_{it} \quad (28)$$

$$\Delta\,ln\,B\,S_{it} = \rho\xi_{it-1} + \sum_{k=1}^{p-1}\pi_k\Delta\,ln\,B\,S_{it-k} + \sum_{k=0}^{q-1}(\beta_k^{+}\,\Delta\,ln\,P\,PT_{it-k}^{+} + \beta_k^{-}\Delta\,ln\,P\,PT_{it-k}^{-}) + \varepsilon_{it} \quad (29)$$

$$\Delta\,ln\,B\,S_{it} = \rho\xi_{it-1} + \sum_{k=1}^{p-1}\pi_k\Delta\,ln\,B\,S_{it-k} + \sum_{k=0}^{q-1}(\lambda_k^{+}\,\Delta\,ln\,G\,HGAS_{it-k}^{+} + \lambda_k^{-}\Delta\,ln\,G\,HGAS_{it-k}^{-}) + \varepsilon_{it} \quad (30)$$

$$\Delta\, ln\, B\, S_{it} = \rho \xi_{it-1} + \sum_{k=1}^{p-1} \pi_k \Delta\, ln\, B\, S_{it-k} + \sum_{k=0}^{q-1} (\alpha_k^{+}\, \Delta\, ln\, C\, CI_{it-k}^{+} + \alpha_k^{-} \Delta\, ln\, C\, CI_{it-k}^{-}) + \varepsilon_{it} \quad (31)$$

$$\text{Where} \xi_{it-1} = ln\, B\, S_{it-1} - \beta^{+}\, ln\, T\, EMP_{it-1}^{+} - \beta^{-}\, ln\, T\, EMP_{it-1}^{+}$$

$$ln\, B\, S_{it-1} - \beta^{+}\, ln\, P\, PT_{it-1}^{+} - \beta^{-}\, ln\, P\, PT_{it-1}^{-}$$

$$ln\, B\, S_{it-1} - \beta^{+}\, ln\, G\, HGAS_{it-1}^{+} - \beta^{-}\, ln\, G\, HGAS_{it-1}^{-}$$

$$ln\, B\, S_{it-1} - \beta^{+}\, ln\, C\, CI_{it-1}^{+} - \beta^{-}\, ln\, C\, CI_{it-1}^{-}$$

5. FINDINGS AND DISCUSSION

5.1. Stationarity Test

The stationarity properties of all variables employed in the study are tested using the Fisher type unit root test. Results of the unit root test are presented in Tables 2 and 3, respectively, for Augmented Dickey-Fuller (ADF) and Phillips Perron (PP). The results show that for both ADF and PP, the stability of banking system and the money supply were non-stationary at constant levels. However, both banking system stability and money supply became stationary at first. On the other hand, greenhouse gas emissions, bank concentration, and regulatory quality were non-stationarity at constant and constant with trend for both ADF and PP in their level forms. As can be observed, the ADF and PP revealed that the aforementioned variables became stationary after first difference. Based on the outcome of the stationarity unit root test, we can confirm the mix order of integration amongst the variables utilized in the study. Tables 2 and 3 summarize the results of the Fisher-type stationarity tests for ADF and PP, respectively.

Table 2. Individual root-fisher ADF unit root test results.

Variables	Test statistics Constant	Test statistics Constant + Trend	Probability values Constant	Probability values Constant + Trend
lnBS	-0.123	-3.156***	0.549	0.000
Δ lnBS	-11.236***	-7.531***	0.000	0.000
lnTEMPT	8.467***	8.408***	0.000	0.000
Δ lnTEMPT	-17.106***	-14.085***	0.000	0.000
lnPPT	10.059***	-7.968***	0.000	0.000
Δ lnPPTs	-16.461***	-13.544***	0.000	0.000
lnGHGAS	1..030	0.505	0.848	0.693
Δ lnGHGAS	9.361***	-7.752***	0.000	0.000
lnCCI	-7.996***	-8.079***	0.000	0.000
Δ lnCCI	-16.728***	-13.829***	0.000	0.000
lnNIM	-5.285***	-3.627***	0.000	0.000
Δ lnNIM	-12.679***	-9.836***	0.000	0.000
lnBC	-1.267	-1.055	0.102	0.145
Δ lnBC	-4.977***	-4.809***	0.000	0.000
lnMS	-1.478	-1.573***	0.930	0.000
Δ lnMS	-10.622***	-7.608***	0.000	0.000
lnRQ	-0.488	-2.424	0.687	0.992
Δ lnRQ	-10.830***	-7.771***	0.000	0.000

Note: *** indicate 1 percent significance level.

Table 3. Individual root-fisher PP unit root test results.

Variables	Test statistics Constant	Test statistics Constant + Trend	Probability values Constant	Probability values Constant + Trend
lnBS	0.308	-3.379***	0.621	0.000
Δ lnBS	-18.802***	-18.652***	0.000	0.000
lnTEMPT	12.583***	-14.599***	0.000	0.000
Δ lnTEMPT	-50.580***	-49.335***	0.000	0.000
lnPPT	16.269***	-15.484***	0.000	0.000
Δ lnPPT	-57.331***	-56.535***	0.000	0.000
lnGHGAS	0.526	0.340	0.700	0.693
Δ lnGHGAS	16.643***	-15.846***	0.000	0.000
lnCCI	-12.191***	-14.172***	0.000	0.000

Variables	Test statistics	Test statistics	Probability values	Probability values
	Constant	Constant + Trend	Constant	Constant + Trend
Δ lnCCI	-48.679***	-46.158***	0.000	0.000
lnNIM	-5.285***	-3.627***	0.000	0.000
Δ lnNIM	-12.679***	-9.836***	0.000	0.000
lnBC	-1.267	-1.055	0.102	0.145
Δ lnBC	-4.977***	-4.809***	0.000	0.000
lnMS	-1.478	-1.573***	0.930	0.000
Δ lnMS	-10.622***	-7.608***	0.000	0.000
lnRQ	-0.488	-2.424	0.687	0.992
Δ lnRQ	-10.830***	-7.771***	0.000	0.000

Note: *** indicate 1 percent significance level.

To kick-start the model application, we employ the Wald test statistics to test the long-term and short-term symmetries of equations 2-5. The symmetric results for both long- and short-term partial sums are presented in Table 4. The Wald test results reveal a discrepancy in the impact of partial sums, both positive and negative, on the stability of the banking system at various long- and short-term levels. The findings support the rejection of the null hypothesis and its alternative. Hence, we deduce that both long-term and short-term asymmetric impact exists for temperature (partial sums). However, the same cannot be said for precipitation. We fail to reject the null hypothesis of no asymmetric impact in the long term. The p-value of precipitation's (positive and negative) partial sums in the long term is insignificant, and no existence of asymmetric impact of precipitation (partial sums) is identified in the long term. Also, the statistics of the short-term impact of precipitation have a different intuition. From Table 4, we observe that the p-value of the test statistics is significant. Therefore, the partial sums of precipitation in the short-term are significant. We surmise that asymmetric impact exists for the partial sums of precipitation in the short-term. With regards to the partial sums of greenhouse gases, we construe that the p-values of both long-term and short-term are significant in their respective significance level. Hence, the partial sums of greenhouse gas differently impact banking system stability at disparate levels. We conclude that there exists an asymmetric impact on the partial sums of greenhouse gases. Finally, we delve into the discussion surrounding the partial sums of the climate change index. We find that the long-term sum of the partial sums of climate change index has no significant probability value. This intuition is an anecdote that there is no asymmetric impact existence with the partial sums of climate change index in the long term. Besides, the Wald test statistics show that the p-value in the short-term was strongly significant, depicting the existence of an asymmetric impact. We present the Wald test statistics results in Table 4.

PPT is precipitation, GHGAS is greenhouse gas, and CCI is climate change index. ln is natural logarithm. LT and ST denote long-term and short-term, respectively. Values in the bracket (.) represent the probability values (P-values). In light of the above discussion on the Wald test statistics presented in Table 3, the intuition conferred requires a statistical assessment to investigate the partial sums (positive and negative) of climate change variables; thus, temperature, precipitation, greenhouse gas, and climate change impact on banking system stability.

Table 4. Wald test results.

Variables	W_{LT}	W_{ST}
	T-statistics	T-statistics
lnTEMPT	1.719 (0.086)*	-4.629 (0.000)***
lnPPT	-1.187 (0.235)	-3.460 (0.000)***
lnGHGAS	-3.4767 (0.000)***	1.8606 (0.063)*
lnCCI	-1.261 (0.207)	2.732 (0.006)***

Note: *** and * represent significance level at 1 and 10 percent, respectively. TEMPT is temperature.

Based on the previous discussions, we conducted a panel non-linear ADRL model and the results are displayed in Table 5. From Table 5, it is revealed that positive and negative partial sums of temperature do not asymmetrically impact banking system stability in both the long-term and short-term. The finding is in contrast with the study of Liu et al. (2021) who reported a negative asymmetric impact between temperature and financial stability. Further, positive and negative partial sums of precipitation negatively impact banking system stability in the long term. Ceteris Paribus, a percentage increase in positive precipitation will dwindle banking system stability by 0.1906 percent. On the other hand, a percentage increase in negative precipitation will reduce banking system stability by 0.3247 percent in the long term, all else unchanged. Further, it is evident from Table 5 that there is no asymmetric impact of partial sums of precipitation in the short-term. In this regard, the negative asymmetric impact of precipitation implies its harmfulness to banking system stability. It is imminent to state that bank branches are relatively exposed to weather conditions; as such, heavy rain is detrimental to the operations of banks. Destruction caused by rainfall will lead to operational damages that cause operational risk, technological risk, and reputational risk and disrupt the stability of banks. A paramount feature in SSA is the local news sensitivity. In Sub-Saharan Africa, the economic sector of which the banking system forms a part is sensitive to local news. For instance, a local news on a heavy downpour affecting a specified bank branch will cause a shock and lead to panic withdrawal of funds, which could destabilized the operations of the bank. This, in turn, impacts both the overall return on assets (ROA) and the return on equity (ROE) at the national level. Despite this, there is ample evidence that climate change significantly impacts agricultural output and farmlands. Moreover, heavy rainfall may cause destruction to agricultural produce and farmlands. It affects agriculture loans or farm loans created by agriculture banks, development banks, and commercial banks who are heavily involved in the agriculture services. Against this backdrop, farmers may default on the loan repayment as chunk of their monetary resources will be channelled to the regrowth and land preparation for the next harvest. The default of loans by farmers adds to the growing ratios of non-performing loans of banks. A significant volume of non-performing loans has the potential to significantly disrupt the stability of banks.

Relying on these insinuations, a typical example can be traced in Burkina Faso, where a heavy downpour (perennial rainfall) induces a spillage from the Bagre Dam to ascertain the required threshold for energy generation. However, this spillage from the Bagre Dam caused by persistent rainfall destroys thousands of hectares of farmlands, livestock, and various agricultural produce, as well as human lives and settlements in the northern part of Ghana. In general, this negative consequence disrupts the agriculture production. Therefore, the repayment processes fail to meet the expectations of farmers who have taken credit facilities from banking institutions for agricultural investments. Further, we posit that negative partial sum of greenhouse gas asymmetrically impacts banking system stability. This means that negative shocks of greenhouse gases reduce banking system stability by 0.983 percent in the short-term. Incongruous with the result of Agbloyor, Dwumfour, Pan, and Yawson (2021) who found a positive relationship between CO_2 and banking system stability. The finding confirms that greenhouse gases pose a significant threat to the stability of the banking system. Importantly, greenhouse gases are chiefly discharged via fossil fuels, natural gases for purposes such as electricity, transportation, and heat, amongst other factors. The development of green products has become a new trend in the banking sector in the wake of climate change waves, for example, green bonds, blue bonds, as well as carbon taxes and its instruments. However, the sensitivity of greenhouse gases is associated with the environment of banks. Most banks use on-grid electricity, which is costly compared to renewable sources of energy. On that note, the Bank for International Settlements (2021) suggests that banks' subjection to climate change has augmented their cost of energy use. This adds to the expenses of banks and affects their profitability. Again, green banking has become the order of the day as banks are mandated to integrate climate change concerns into their operations. This new movement has become challenging for some banks, and they keep struggling with the design and implantation in line with the new trend. In Sub-Saharan Africa, the adaptation of climate change concerns in the banking sector is highly marginal. Most banks in the sub-region have customers who operate in a greenhouse gas-prone environment, for example, mining (legal and illegal), oil and gas companies and the manufacturing sector, etc. An exclusion list created by central banks to help integrate climate change challenges will hamper stability and operations of the banking sector. These companies have large amount of money deposited in their accounts. Moreover, these companies borrow a significant amount (due to their good credit history and low level of credit default) and repay at a faster rate to help sustain their respective operations. A stringent exclusion procedure will deter these companies from depositing huge sums of money in their respective banks as banking regulations will become tighter for companies operating in the aforesaid field. Tighter regulations in view of climate change integration in the banking sector will phase out some companies, and this will affect the operational balances as well as the profitability of banks, crippling the stability of the banking sector. As part of the rules for a sustainable and responsible banking system, central banks will not be able to require all banks to include climate change impacts in their work. This will limit the amount of money that banks give to companies that release greenhouse gases. In effect, the financial transactions from these emitting companies will reduce, hence, dwindling banks liquidity. It should be borne in mind that most of these emitting companies have chunks of money with their respective banks.

Climate change index, on the other hand, indicates that positive and negative partial sums of climate change index asymmetrically impact banking system stability in the long term. This is an indication that positive shocks of climate change index hinder banking system stability by 0.036 percent, all things being equal. Further, a negative shock of climate change index hampers banking system stability by 0.083 percent, holding other factors constant. The finding is in accord with the work of Liu et al. (2021) who find that both positive and negative climate change harm financial stability. Globally, climate change is considered one of the risks that hampers banking activities. The former Bank of England governor, Carney (2015) unveils that climate change is the next cause of global financial crunch. Undeniably, climate change poses numerous risks that affect the operations of the banks, thereby affecting the stability of banks. The control variables, such as net interest margin, have significant positive long-term and short-term impact on banking system stability in all equations (24-27). Thus, a percentage increase in net interest margin will increase banking system stability by 0.378 percent, 0.295 percent, 0.342 percent, as well as 0.373 percent in the long term. On average a percentage increase in net interest margin in the short-term will increase banking system stability by 0.155 percent, 0.150 percent, 0.148 percent, and 0.140 percent for the four models, respectively. Furthermore, bank concentration had a significant negative relationship in both long-term and short-term. Ceteris paribus, an increase in bank concentration will decrease banking system stability by 0.111 percent, 0.038 percent, 0.083 percent, and 0.097 percent in the long term for respective models. In the context of the short-term impact, banking system stability will drop by 0.140 percent, 0.148 percent, 0.128 percent, and 0.108 percent with a percentage increase in bank concentration.

Money supply elicits a significant positive and negative relationship with banking system stability in the long term; however, an insignificant relationship was established in the short term. The significant relationship suggests that when money supply rises by a percentage point, banking system stability will increase by 0.054 percent and decrease by 0.055 percent in the long-term for both equations 26 and 25, respectively. In terms of regulatory quality, a significant negative relationship with banking system stability is observed in equations 24, 26, and 27 in the long term. Nonetheless, a percentage increase in regulatory quality will reduce banking system stability by 0.167 percent in equation 24, 0.233 percent in equation 26, and 0.150 percent in equation 27. The finding is in line with the study of Cobbinah, Zhongming, and Ntarmah (2020) who found a negative link between regulatory quality index and banking system stability. The results show that Sub-Saharan economies are very pallid and not conducive to enhancing the growth of the banking sector. Importantly, regulatory quality was insignificant for all models in the short-term impact. On that note, we present the asymmetric results in Table 5.

Table 5. Asymmetric test results.

Equations	Equation 24		Equation 25		Equation 26		Equation 27	
Long-term impact								
Variable	**Coefficient**	**Std. error**	**Coefficient**	**Std. error**	**Coefficient**	**Std. error**	**Coefficient**	**Std. error**
$lnTEMPT^{+}$	0.002	0.020 (0.919)						
$lnTEMPT^{-}$	-0.010	0.021 (0.616)						
$lnPPT^{+}$			-0.190	0.086** (0.027)				
$lnPPT^{-}$			-0.324	0.081*** (0.000)				
$lnGHGAS^{+}$					0.014	0.063 (0.822)		
$lnGHGAS^{-}$					-0.048	0.054 (0.369)		
$lnCCI^{+}$							-0.036	0.015** (0.022)
$lnCCI^{-}$							-0.083	0.017*** (0.000)
lnNIM	0.378	0.018*** (0.000)	0.295	0.012*** (0.000)	0.342	0.018*** (0.000)	0.373	0.017*** (0.000)
lnBC	-0.111	0.011*** (0.000)	-0.038	0.007*** (0.000)	-0.083	0.013*** (0.000)	-0.097	0.010*** (0.000)
lnMS	-0.002	0.023 (0.924)	-0.055	0.014*** (0.000)	0.054	0.021** (0.012)	0.028	0.019 (0.147)
lnRQ	-0.167	0.048*** (0.000)	-0.016	0.031 (0.595)	-0.233	0.046*** (0.000)	-0.150	0.042*** (0.000)
Short-term impact								
$\Delta lnTEMPT^{+}$	-0.015	0.021 (0.484)						
$\Delta lnTEMPT^{-}$	0.038	0.039 (0.325)						
$\Delta lnPPT^{+}$			-0.062	0.154 (0.684)				
$\Delta lnPPT^{-}$			0.102	0.159 (0.520)				
$\Delta lnGHGAS^{+}$					-0.038	0.246		

Equations	Equation 24		Equation 25		Equation 26		Equation 27	
Long-term impact								
Variable	**Coefficient**	**Std. error**	**Coefficient**	**Std. error**	**Coefficient**	**Std. error**	**Coefficient**	**Std. error**
						(0.875)		
Δ $\ln GHGAS^-$					-0.983	0.474** (0.039)		
Δ $\ln CCI^+$							0.027	0.038 (0.485)
Δ $\ln CCI^-$							0.000	0.037 (0.981)
Δ lnNIM	0.155	0.042*** (0.000)	0.150	0.045*** (0.000)	0.148	0.045*** (0.001)	0.140	0.044*** (0.001)
Δ lnBC	-0.140	0.066** (0.035)	-0.148	0.062** (0.017)	-0.128	0.067* (0.057)	-0.108	0.067 (0.105)
Δ lnMS	-0.080	0.066 (0.225)	-0.013	0.185 (0.942)	0.013	0.117 (0.910)	-0.018	0.131 (0.888)
Δ lnRQ	0.225	0.024 (0.689)	0.057	0.073 (0.438)	0.053	0.077 (0.492)	0.027	0.083 (0.745)
ECT	-0.384	0.065*** (0.000)	-0.499	0.057*** (0.000)	-0.411	0.065*** (0.000)	-0.384	0.074*** (0.000)
C	1.071	0.1940*** (0.000)	1.327	0.157*** (0.000)	0.991	0.1609*** (0.000)	0.952	0.188*** (0.000)

Note: *** and ** indicate the significance level at 1 percent and 5 percent, respectively. The value in brackets (.) measures the respective probability values (P-values) of the variables adjusted sample size from 1996 to 2017. Akaike information criterion lag selection. (+) measures positive partial sums and (-) is the negative partial sums. TEMPT (Temperature), PPT(Precipitation), GHGAS (Greenhouse gas emissions) CCI (Climate change index), NIM (Net interest margin), BC (Bank concentration), MS (Money supply), RQ (Regulatory quality). ln measures natural logarithm of respective variables. ECT (Error correction term) and C (Intercept).

6. CONCLUSION

Globally the issue of climate change has grown in importance. In recent years, research on the impact of climate change on financial institutions and markets has increased. According to the European Investment Bank (2013) sub-Saharan economies experience the greatest repercussions of climate change, although they are considered the least emitters. For example, the World Metrological Organization (2019) says that SSA experienced extreme weather events that impacted business activities. An analysis of climate risk regulation in twelve African countries by United Nations Environment Programme Initiative (UNEPI) revealed that some countries in Africa have no climate risk initiatives. For instance, the Central Banks of the Democratic Republic of Congo, Rwanda, and Union Monétaire Ouest Africaine members have no regulations on climate risks. Notwithstanding, countries such as Ghana, Kenya, Mauritius, Nigeria, South Africa, and Zimbabwe are sub-Saharan economies whose central banks have developed principles to guide banking operations in line with climate change implications.

Motivated by this notion, the study explores the asymmetric impact of climate change on banking system stability with annual data from 29 selected sub-Saharan economies that spans 1996-2017. The study employs a panel non-linear autoregressive distributed lag (NARDL) model and finds that partial sums (positive and negative) of temperature reported an insignificant relationship with banking system stability in the long term. In addition, the study disclosed that partial sums of precipitation (positive and negative) had a significant negative relationship with banking system stability in the long term. The finding indicates that both positive and negative precipitation do harm banking system stability in selected sub-Saharan economies. Further, we find that partial sums (positive and negative) of greenhouse gas had an insignificant effect on banking system stability. We conclude that greenhouse gases (positive and negative) do not impair banking system stability in selected sub-Saharan economies in the long term. We surmise from the findings that partial sums (positive and negative) of climate change index are nocuous to banking system stability. The evidence is based on the premise that in the long-term, positive and negative climate change index had a negative and significant connection with banking system stability. Casting the discourse on the short-term asymmetric impact, we discover that partial sums (positive and negative) of temperature, precipitation, and climate change index do not harm banking system stability with a reported insignificant coefficient, respectively. However, negative greenhouse gas is pernicious to the banking system's stability in the short-term. Thus, negative greenhouse gas has a negative relation with banking system's stability in the short term. However, positive greenhouse gas emissions reported an insignificant nexus with banking system stability.

7. RECOMMENDATIONS AND POLICY IMPLICATIONS

The study recommends that central banks and monetary authorities in SSA should design green banking policies to push the climate change agenda in the banking sectors. One palpable way of controlling the impact of climate change on banking system stability is via extenuation. Green financing has emerged as a new trend to mitigate the impact of climate change on banking system operations. In addition, green finance has the propensity to alleviate the financial risks in line with the swift adaptation to low-carbon economy. Central banks can create policies such as green quantitative easing and prudent financial regulations (macro and micro regulations) that could oversee green finance initiatives. Green products such as green mortgages, green commercial loans (building loans), green car loans, green cards (debit and credit cards), green insurance, and carbon insurance should be available in the banking sectors of Sub-Saharan economies with the backing of the central banks and monetary authorities.

Furthermore, agriculture in SSA is mainly rain-fed, which enhances food production in the region. However, low irrigation system is predominant in the region, which affects the yields of crops, thereby affecting economic and financial transactions of farmers and suppliers. On that account, the study recommends that governments in various Sub-Saharan economies should enact policies to boost the irrigation systems of agriculture and its allied activities. An increase in agriculture yields increases demand deposits of banks, thereby increasing the liquidity of banks. Therefore, it reduces the credit risk exposure of banks as agriculture agents are able to repay their loans. This tends to increase the stability of banks. Again, governments should partner with the private sector in a public-private partnership (PPP) to develop small-scale irrigation infrastructure or irrigation dams in a demand-driven way. In this context, government will subsidize the cost of the irrigation infrastructure while farmers pay a lesser amount over a period of time.

8. LIMITATIONS AND DIRECTION OF FUTURE RESEARCH

The study made a significant effort to investigate the asymmetric chemistry between climate change and banking system stability in selected sub-Saharan economies. However, the study has limitations in certain areas that necessitate further attention. Due to a lack of data, the study could not cover all 48 sub-Saharan economies. In light of this, it would make a significant empirical contribution if the research is extended to cover all economies in SSA.

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REFERENCES

Africa Development Bank. (2019). *Climate change in Africa.* Retrieved from https://www.afdb.org/en/cop25/climate-change-africa

Agbloyor, E. K., Dwumfour, R. A., Pan, L., & Yawson, A. (2021). *Carbon emissions and banking stability: Global evidence (No. 111092).* University Library of Munich, Germany.

Allianz Global Investors. (2024). *Climate change: Banking on a greener future.* Retrieved from https://www.allianzgi.com/en/insights/outlook-and-commentary/climate-change

Amo-Bediako, E., Takawira, O., & Choga, I. (2023). The impact of climate change on the resilience of banking systems in selected Sub-Saharan economies. *International Journal of Applied Economics, Finance and Accounting, 17*(2), 469-482. https://doi.org/10.33094/ijaefa.v17i2.1203

Amo-Bediako, E., Takawira, O., & Choga, I. (2024). Does macroeconomic transmission streams matter for climate change and banking system stability relationships in selected Sub-Saharan economies? *International Journal of Applied Economics, Finance and Accounting, 19*(2), 227-241. https://doi.org/10.33094/ijaefa.v19i2.1696

Anderl, C., & Caporale, G. M. (2022). Nonlinearities and asymmetric adjustment to PPP in an exchange rate model with inflation expectations. *Journal of Economic Studies, 49*(6), 937-959. https://doi.org/10.2139/ssrn.3798942

Arize, A. C., Malindretos, J., & Igwe, E. U. (2017). Do exchange rate changes improve the trade balance: An asymmetric nonlinear cointegration approach. *International Review of Economics & Finance, 49*, 313-326. https://doi.org/10.1016/j.iref.2017.02.007

Bank for International Settlements. (2021). *Climate-related risk drivers and their transmission channels.* Retrieved from https://www.bis.org/bcbs/publ/d517.pdf

Carney, M. (2015). Breaking the tragedy of the horizon–climate change and financial stability. *Speech Given at Lloyd's of London, 29*, 220-230.

Cobbinah, J., Zhongming, T., & Ntarmah, A. H. (2020). Banking competition and stability: Evidence from West Africa. *National Accounting Review, 2*(3), 263-284. https://doi.org/10.3934/nar.2020015

Correa, R., He, A., Herpfer, C., & Lel, U. (2022). *The rising tide lifts some interest rates: Climate change, natural disasters, and loan pricing.* International Finance Discussion Paper. No. 1345.

De Bandt, O., Jacolin, L., & Thibault, L. (2021). Climate change in developing countries: Global warming effects, transmission channels and adaptation policies.

European Investment Bank. (2013). *Banking in Sub-Saharan Africa-challenges and opportunities*. Retrieved from https://www.eib.org/attachments/efs/economic_report_banking_africa_en.pdf

Fang, Y., Yin, J., & Wu, B. (2016). Flooding risk assessment of coastal tourist attractions affected by sea level rise and storm surge: A case study in Zhejiang Province, China. *Natural Hazards, 84*, 611-624. https://doi.org/10.1007/s11069-016-2444-4

Fard, A., Javadi, S., & Kim, I. (2020). Environmental regulation and the cost of bank loans: International evidence. *Journal of Financial Stability, 51*, 100797. https://doi.org/10.1016/j.jfs.2020.100797

Gatti, D. D., Gallegati, M., & Minsky, H. P. (1996). Financial institutions, economic policy, and the dynamic behavior of the economy. *Behavioral Norms, Technological Progress, and Economic Dynamics: Studies in Schumpeterian Economics, 5*, 393. https://doi.org/10.2139/ssrn.125848

Javadi, S., & Masum, A.-A. (2021). The impact of climate change on the cost of bank loans. *Journal of Corporate Finance, 69*, 102019. https://doi.org/10.1016/j.jcorpfin.2021.102019

Kalecki, M. (2013). *Theory of economic dynamics*. London: Routledge.

Kaur Brar, J., Kornprobst, A., Braun, W. J., Davison, M., & Hare, W. (2021). A case study of the impact of climate change on agricultural loan credit risk. *Mathematics, 9*(23), 3058. https://doi.org/10.3390/math9233058

Keen, S. (2020). Emergent macroeconomics: Deriving minsky's financial instability hypothesis directly from macroeconomic definitions. *Review of Political Economy, 32*(3), 342-370. https://doi.org/10.1080/09538259.2020.1810887

Keynes, J. M. (1937). The general theory of employment. *The Quarterly Journal of Economics, 51*(2), 209-223.

Khurshid, N., Fiaz, A., Khurshid, J., & Ali, K. (2022). Impact of climate change shocks on economic growth: A new insight from non-linear analysis. *Frontiers in Environmental Science, 10*, 1039128. https://doi.org/10.3389/fenvs.2022.1039128

King, J. (2013). Hyman minsky and the financial instability hypothesis. *Wirtschaft und Gesellschaft, 39*(4), 485-508.

Kousky, C., Palim, M., & Pan, Y. (2020). Flood damage and mortgage credit risk: A case study of Hurricane Harvey. *Journal of Housing Research, 29*(sup1), S86-S120. https://doi.org/10.1080/10527001.2020.1840131

Kregel, J. (2018). *Preventing the last crisis: Minsky's forgotten lessons ten years after Lehman*. Levy Economics Institute. No. 18-5.

Lavoie, M. (2016). Understanding the global financial crisis: Contributions of Post-Keynesian economics. *Studies in Political Economy, 97*(1), 58-75. https://doi.org/10.1080/07078552.2016.1174463

Le, A.-T., Tran, T. P., & Mishra, A. V. (2023). Climate risk and bank stability: International evidence. *Journal of Multinational Financial Management, 70*, 100824. https://doi.org/10.1016/j.mulfin.2023.100824

Liu, Z., Sun, H., & Tang, S. (2021). Assessing the impacts of climate change to financial stability: Evidence from China. *International Journal of Climate Change Strategies and Management, 13*(3), 375-393. https://doi.org/10.1108/ijccsm-10-2020-0108

Maphosa, M. (2020). *Lending booms and bank fragility: The South African experience*. Doctoral Dissertation, Stellenbosch: Stellenbosch University.

Marshall, W. C. (2021). A friendly critique of minsky's financial instability hypothesis. *International Journal of Political Economy, 50*(4), 257-271.

Mckinsey & Company. (2020). *Mckinsey on climate change*. Retrieved from https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/McKinsey%20on%20Climate%20Change/McKinsey-on-Climate%20Change-Report.pdf

Miller, R. A. (2018). Minsky's financial instability hypothesis and the role of equity: The accounting behind hedge, speculative, and Ponzi finance. *Journal of Post Keynesian Economics, 41*(1), 126-138. https://doi.org/10.1080/01603477.2017.1392870

Minsky, H. P. (1977). The financial instability hypothesis: An interpretation of Keynes and an alternative to "standard" theory. *Challenge, 20*(1), 20-27. https://doi.org/10.1080/05775132.1977.11470296

Minsky, H. P. (1992). *The capitalist development of the economy and the structure of financial institutions*. The Jerome Levy Economics Institute Working Paper. No. 72.

Mulligan, R. F. (2013). A sectoral analysis of the financial instability hypothesis. *The Quarterly Review of Economics and Finance, 53*(4), 450-459. https://doi.org/10.1016/j.qref.2013.05.010

Mulligan, R. F., Lirely, R., & Coffee, D. (2014). An empirical examination of Minsky's financial instability hypothesis: From market process to Austrian business cycle. *Journal des Economistes et des Etudes Humaines, 20*(1), 1-17. https://doi.org/10.1515/jeeh-2013-0005

National Whistleblower Centre. (2024). *Global climate whistle blower center.* Retrieved from https://www.whistleblowers.org/global-climate-whistleblower-center/

Nie, O., Regelink, M., & Wang, D. (2023). *Banking sector risk in the aftermath of climate change and environmental-related natural disasters.* Washington, DC: World Bank.

Omoke, P. C., Opuala-Charles, S., & Nwani, C. (2020). Symmetric and asymmetric effects of financial development on carbon dioxide emissions in Nigeria: Evidence from linear and nonlinear autoregressive distributed lag analyses. *Energy Exploration & Exploitation, 38*(5), 2059-2078. https://doi.org/10.1177/0144598720939377

Perepelkina, E., & Rozmainsky, I. (2023). Empirical analysis of the financial fragility of Russian enterprises using the financial instability hypothesis. *Journal of Post Keynesian Economics, 46*(2), 243-273. https://doi.org/10.1080/01603477.2022.2134036

Reis, M., & Vasconcelos, D. (2016). The legal theory of finance and the financial instability hypothesis: Convergences and possible integration. *Journal of Post Keynesian Economics, 39*(2), 206-227. https://doi.org/10.1080/01603477.2016.1165622

Rozmainsky, I., Kovezina, Y., & Klimenko, A. (2022). An empirical application of the financial instability hypothesis based on data from the Dutch non-financial private sector. *Journal of Post Keynesian Economics, 45*(2), 281-300. https://doi.org/10.1080/01603477.2021.1993072

Sandoval, P. G. (2017). *Masters finance thesis empirical analysis of the minsky's financial instability hypothesis in USA: 2000-2017.* Retrieved from http://arno.uvt.nl/show.cgi?fid=144932

Scott, M., van Huizen, J., & Jung, C. (2017). The bank's response to climate change. *Bank of England Quarterly Bulletin, 57*(2), 98-109.

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. *Festschrift in Honor of Peter Schmidt: Econometric Methods and Applications*, 281-314. https://doi.org/10.1007/978-1-4899-8008-3_9

Sun, Y., Yang, Y., Huang, N., & Zou, X. (2020). The impacts of climate change risks on financial performance of mining industry: Evidence from listed companies in China. *Resources Policy, 69*, 101828. https://doi.org/10.1016/j.resourpol.2020.101828

Torres Filho, E. T., Martins, N. M., & Miaguti, C. Y. (2019). Minsky's financial fragility: An empirical analysis of electricity distribution firms in Brazil (2007–2015). *Journal of Post Keynesian Economics, 42*(1), 144-168. https://doi.org/10.1080/01603477.2018.1503057

U-Din, S., Nazir, M. S., & Shahzad, A. (2023). Money at risk: Climate change and performance of Canadian banking sector. *Journal of Economic and Administrative Sciences, 39*(2), 273-285. https://doi.org/10.1108/jeas-02-2021-0033

World Metrological Organization. (2019). *WMO statement on the state of the global climate in 2019.* Retrieved from https://library.wmo.int/doc_num.php?explnum_id=10211#:~:text=The%20year%202019%20ended%20with,of%20the%20ongoing%20climate%20change

Zhang, W. L., Chang, C. P., & Xuan, Y. (2022). The impacts of climate change on bank performance: What's the mediating role of natural disasters? *Economic Change and Restructuring*, 1-40. https://doi.org/10.1007/s10644-021-09371-3

Zhang, X., Zhang, M., & Fang, Z. (2023). Impact of climate risk on the financial performance and financial policies of enterprises. *Sustainability, 15*(20), 14833. https://doi.org/10.3390/su152014833

Zhou, S. (2019). *Shadow banking, financial stability and economic performance: Implications for regulation in emerging economies.* Doctoral Dissertation, University of Zululand.

Appendix 1. List of countries.

Countries	
Angola	Namibia
Burkina	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	