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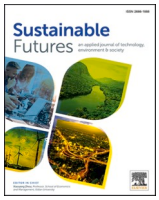

Climate risk and financial stability in Africa: A comparative study before and during the Paris agreement

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ABSTRACT

This study examines the impact of climate risk (CRI)[1] on the financial stability of African countries (AFC), measured by their ZScore, before and during the enactment of the Paris Agreement (PAG) and for the period 2010–2019. It also explores the impact of their governance system on the relationship between CRI and financial stability. Data from thirty-two African countries and various regression analyses were estimated for the study. Robust analyses were used to validate the findings. The study found that before, during the enactment of the PAG and for the period 2010–2019, CRI had no impact on the financial stability of AFC. Additionally, their governance system did not impact on the relationship between CRI and financial stability. As AFC face severe challenges, coupled with the fact that CRI exposure had no significant impact on AFC financial stability following the enactment of the PAG, in addition, the fact that their governance mechanisms do not mitigate CRI exposure, highlights the urgent need to integrate climate risk exposure in the financial monitoring system of African countries and the need to address the challenges that AFC face. To the author's knowledge, this study is the first to examine the impact of CRI on the financial stability of AFC considering the enactment of the PAG and how other mechanisms impact their CRI exposure and their financial stability.

Paris Agreement recognize the specific needs and special circumstances of developing countries, especially those that are particularly vulnerable to the adverse effects of climate change [1]. In addition, The Paris Agreement acknowledge that climate change is a common concern of humankind, and countries should take action to address climate change, respect, promote and consider their respective obligations on human rights, including the right to development [1].

The development of African countries depends on the financial stability of their banking system [2]. Financial stability promotes business development, facilitates investment, provides credit to drive economic growth, creates jobs, facilitates the development of projects, helps in funding activities to mitigate climate risk exposure and promotes financial inclusion by providing access to financial services, such as banking, credit, and savings [3–5]. In addition, cross-broader banking integration makes financial stability a major concern for policymakers in Africa. However, climate risk exposure resulting in physical damage and causalities or changes in climate policy can negatively or positively impact the financial stability or income of African countries (e.g. [6]) and African countries face significant climate risk exposure [7]. Climate change poses significant economic risks [8], exacerbating poverty [9] and undermining financial stability. Countries failing to institute measures to mitigate climate risk exposure would experience bad impacts resulting from climate risk exposure.

On the other hand, countries considering climate risk exposure in their risk management systems, decisions and policies and actively managing by instituting measures would improve their financial stability. As, Ashraf and Shen [10] recently, argue that there are challenges and opportunities associated with climate risk. The Paris Agreement was enacted to help countries, including African countries to mitigate climate risk exposure. The Paris Climate Agreement was established in 2015 to focus on the risks of climate change to the environment and society [11]. This brings to bear how climate risk exposure has impacted African countries' financial stability following the enactment of the Paris Agreement. The Paris Agreement as part of its aim is to help

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[1] CRI is Climate risk , AFC is African countries, ZSC is Z-score, BOA is Bank return on Assets , PCP is Private Credit to GDP ratio, CON is Bank concentration, BDP is Bank deposit to GDP, GDP is GDP per capita , GDG is GDP growth, INF is Inflation rate, COC is Control of Corruption, GOE is Government Effectiveness, POS is Political Stability, RGQ is Regulatory Quality, VOA is Voice and Accountability and ROL is Rule of Law

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developing countries mitigate climate risk exposure.

On 12 December 2015, the Paris Agreement was signed at the Paris Climate Conference and entered into force on 4 November 2016. Prior research has indeed acknowledged that the enactment of the Paris Agreement impacts the climate risk and financial stability relationship, for instance, from an international perspective, Liu et al., [4] found that climate risk negatively affects financial stability and consider that the signing of the Paris Agreement was likely to change their research results. The study sample included only about 12 African countries. Also, le et al., [12] investigated climate risk and its impact on bank stability with a sample of 109 countries including some African countries and they made assertions that the Paris Agreement is a reference point for starting discussions on climate-related financial risks and its impact on financial stability. However, Böhringer et al. [13] argue that after the Paris Agreement Climate policies in aligning Nationally Determined Contributions with the 2 °C target set by the Paris Agreement induce global economic costs of roughly 1 % in 2030. Also, Li and Pan [14], evidenced that after the Paris Agreement, the negative impact of climate risk exposure on Chinese commercial banks was reduced, thus improving the country's financial stability. The study focuses on the Chinese economy. Indeed, other researchers have also confirmed the enactment of the Paris Agreement to be a game changer in climate risk management and financial stability (e.g., [15,16]). Although prior research has examined the impact of the Paris Agreement on climate risk and bank stability, there is little empirical evidence concerning climate risk's impact on financial stability focusing on African countries. In addition, literature has not examined how climate risk impacted African countries' financial stability before the Paris Agreement as compared to during the implementation of the Paris Agreement. Furthermore, no literature has focused on African countries taking into consideration their financial development, competitive environment, and governance mechanisms in examining the impact of climate risk exposure on their financial stability. Therefore, this study aims to fill this research gap by examining African countries' climate risk exposure its impact on their financial stability and examining their financial, competitiveness and governance systems in this relationship from the theoretical perspective of the sustainability transition.

Understanding the impact of climate risk on African country's bank stability is relevant for the following reasons. Firstly, African countries are faced with peculiar socio-economic challenges different as compared to other continents and this study would help to know how African countries are coping with the impact of their climate risk on their financial stability in the challenging environment, they found themselves in, following the enactment of the Paris agreement with require global decarbonization. Secondly, the financial development and competitive environment African countries find themselves in is also different from other continents and knowing how these factors play a role in climate risk and financial stability would help African governments and regulators when initiating policies on African climate risk and financial stability matters. Thirdly, the national governance system in Africa is completely different from other continents, therefore analysing the impact of climate risk on African countries in their context of governance system would help to know how their governance system impacts their financial stability. Finally, information released by Germanwatch indicates that African countries considered by this study show mixed impact of climate risk exposure. About half of the countries are less impacted by climate risk (i.e. showing a reducing trend), while the other half are also showing a deteriorating impact of climate risk (i.e. increasing trend) (see Fig. 1). This study would help investigate how African countries' climate risk exposure impacts their financial stability following the Pais Agreement, as Elliott and Löfgren [17] observed that banks have stated an increasing number of climate change actions since the introduction of the Paris Agreement. They observed that there are few clear commitments on their part concerning their responsibility for

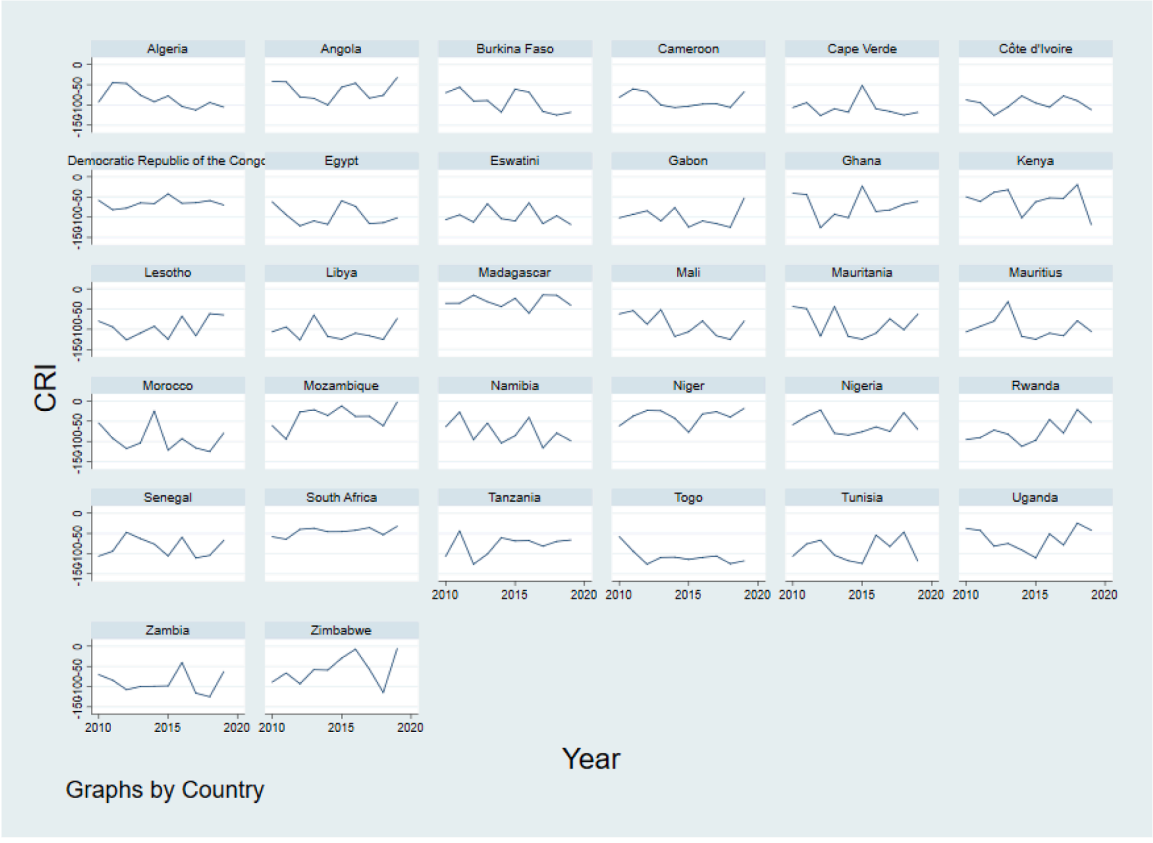

Fig. 1. African countries climate risk exposure reported by the GermanWatch organization.

financing climate change, so is that the case of African country's financial regulators and governance system in relationship to climate risk exposure and financial stability, following the Paris Agreement?

Fig. 1: African countries climate risk exposure reported by the GermanWatch organization

Therefore, to examine the climate risk and financial stability relationship for African countries the paper focuses on 32 African countries. The study relies on Liu et al. [4], in the classification of during the Paris agreement period (2015–2019), while the period (2010–2014) is used for comparison purposes. The study also considers the full period (2010 to 2019) and examines (1) the impact of climate risk on financial stability; and (2) how governance mechanisms influence the climate risk and financial stability relationship. In addition, heterogeneity analysis concerning the impact of financial development and competition environment are examined.

This paper contributes to the literature. First, it tries to give theoretical support to the sustainability transition theory in helping to understand the impact of climate risk on the financial stability of African countries and also considering the enactment of the Paris Agreement and its governance system impacting on its climate risk and financial stability relationship. Furthermore, it explores how African countries' financial development, and their competitive environment impact their climate risk and financial stability relationship. To the author's knowledge, this paper is the first to explicitly examine climate risk on financial stability focusing on African countries. Secondly, the study is the first to explore the impact of climate risk on financial stability in African countries considering the enactment of the Paris Agreement by carrying out pre- and post-analysis of climate risk on financial stability following the Paris Agreement enactment in African countries facing peculiar economic challenges. Bolton et al. [18] and FSB [19] assert that there has been growing debate on the relationship between climate risk and financial stability following the Paris Agreement. Although the study uses a sample up till 2019, the study provides valuable guidance for policymakers, African governments, financial institutions and other stakeholders, highlighting the importance of incorporating climate risk mitigation into financial decision-making and developing strategies to promote financial stability in Africa. Thus, this contributes to the ongoing discussion on climate risk and promoting financial stability in Africa and offers practical insights for stakeholders to address these challenges. Thirdly, this study adds to the literature on the impact of financial development and competitive environment on the climate risk and financial stability relationship from the African perspective. Finally, the study helps to understand how the peculiar national governance system in African countries impacts climate risk and financial stability. Therefore, the moderating role of the national governance system in the climate risk and financial stability relationship from African countries perspective is investigated.

This paper is organized as follows. Section 2 looks at the theoretical framework and reviews the relevant literature; Section 3 describes the methodology. Section 4 reports and discusses the results. Section 5 considers the discussion and the research implications. Section 6 reports limitations and future research avenues.

1. Theoretical framework and literature review

1.1. Theoretical framework

The study is grounded in the sustainability transition theory which helps to explain systemic changes towards more sustainable societies [20,21]. The theory helps to explain how socio-technical systems change can help to address environmental and social challenges, including changes in technology, markets, values, and institutions [22]. In the context of the study considering climate risk mitigation, the good recommendations of the Paris Agreements, and effective governance system by African countries in their financial management system by identifying and managing potential impacts from climate-related events, to minimize its negative impacts and maximize opportunities associated with it, all things being equal would help to address the environmental and social challenges of the continent and help improve its financial stability. For example, incorporating technology and innovation in climate risk mitigation, ensuring effective climate risk mitigation policies at the national and local level, committing to the requirements of the Paris Agreement following its enactment, and promoting good governance would help in its climate risk mitigation impacting positively on its financial stability. Indeed, the African Financial Alliance on Climate Change emphasize the need for African countries to integrate climate risk into their financial decision-making, which will improve their financial stability. In addition, there is a need for them to promote an effective governance system in their quest for climate risk mitigation to have a positive impact on their financial system [23].

Prior research has also emphasized the impact of climate risk mitigation on financial stability from the theoretical point of sustainability transition. Geels et al. [24], Semieniuk et al. [25], and Porfiriev [26] emphasize that transitioning to a low-carbon economy, which includes climate risk mitigation and adopting sustainable finance practices improves financial stability. Other strands of literature have also stressed climate risk mitigation, the Paris Agreement, and effective governance systems having an impact on financial stability. For example, in the eurozone, Giuzio et al. [27] emphasize that climate risk can potentially impact their financial stability especially if markets are not pricing or considering the risks correctly. Also, other researchers have emphasized the positive impact of the Paris Agreement and governance system on the climate risk and financial stability relationship in other countries and continents (e.g., [12,14–16]).

Although prior research has helped in the understanding of the impact of climate risk and the Paris Agreement on financial stability (e.g. [14]), from the theoretical point of sustainability transition, how climate risk and the consideration of the Paris Agreement impacting Africa countries financial stability little is known about it. Also, from the theoretical view of sustainability transition how the governance system of African countries does impact the climate risk and their financial stability relationship little is known about it. Because most African countries are in transition to achieving low carbon economy [28], by improving their climate risk mitigation to help improve their financial stability. Thus, the study aims to fill this research gap from the theoretical view of sustainability transition by examining the impact of African country's climate risk on their financial stability before the enactment of the Paris Agreement (i.e. for the period 2010 to 2014) and compare it to after the enactment of the Paris Agreement (i.e. for the period 2015 to 2019). Also, the study examines the impact of African country's governance systems on their climate risk and financial stability relationship for the period (2010 to 2019). That is their governance system as an institutional framework in facilitating sustainable transition. The study further explores the impact of their financial development and their competitive environment on their climate risk and financial stability relationship for the period (2010 to 2019), as a sustainable transition mechanism.

The next sections developed the hypothesis by reviewing the relevant literature on CRI and financial stability, the signing of the Paris Agreement and its impact on climate risk and financial stability. In addition, review relevant literature on the governance mechanisms of the CRI and financial stability relationship.

1.2. CRI and financial stability

Extant literature has established that indeed climate risk does impact the financial stability of countries. Climate risk resulting from physical damage and causalities may affect the value of assets or financial assets held by firms or countries. This would affect the liquidity, and leverage of financial institutions within a country impacting their financial stability. Recently in the USA, Liang et al. [29] observed that climate policy uncertainty on US economic and financial market stability is weak, and

it only strengthens under some circumstances, particularly from a long-term perspective. In another recent study, Sari [30] argued that climate risk costs US$143 billion per year and that losses created because of no action on climate change could amount to US$178 trillion in 2070. This would disrupt the financial stability of countries impacted by climate risk exposure. In China, Meng et al., [31] concluded that Climate policies like carbon tax and green supporting factors influence China's financial stability, with initial negative effects but on a long-term basis do improve the financial stability. Also, in Turkiye, Joof and Isiksal [32] found that climate risk of physical and transition risks impacted the financial stability of Türkiye from 1980 to 2020 through natural disasters' frequency, while environmental taxes and technologies can enhance financial stability. In European financial markets, Chabot et al. [33] identified that climate risks directly impact non-financial companies and indirectly affect financial institutions, thus impacting the financial stability within the European financial markets.

From the global perspective, Jiang [8] evaluated 167 countries (1850–2018) and identified two climate-economic growth patterns: Convergent growth, that is, economic growth and climate change stabilize over time and divergent growth, that is, economic growth and climate change increasingly diverge, leading to unstable growth. These patterns have significant implications for nations' financial stability. Also, Mandel et al. [34] asserted that Climate change-induced extreme weather events, like floods, can threaten global financial stability by amplifying impacts in highly leveraged high-income countries, potentially leading to systemic risks through financial network connectivity. In examining G-5 nations, Sun et al. [35] determined the impact of financial stability on climate risk in effectively managing climate mitigation efforts in G-5 nations. They found climate change mitigation to be substantial at 18 %, while financial stability and carbon hazards were found significant at 21 %. In another study, Zhang et al. [36] examined firms in 37 countries from 2017 to 2021. They found that climate risk impacts financial stability by showing a negative correlation with firm performance but found a positive association with long-term debt, influencing financial policies and performance in different countries, thus impacting their financial stability. The Global financial report observed that Climate risks impact financial stability by increasing vulnerabilities in emerging markets [37].

From the African perspective, Abidoye and Odusola [38] examined the linkage between economic growth and climate change in Africa, focusing on 34 countries from 1961 to 2009, they found a negative impact of climate change on economic growth and concluded that a 1 °C increase in temperature reduces gross domestic product (GDP) growth by 0.67 percentage point. Considering the interaction effects within an economy and the impact of globalization this would impact negatively African countries' financial stability. In Uganda, Mawejje [39] observed that climate risk exposure negatively impacts business performance, which reasonably would negatively impact the country's financial stability of the country. Focusing on African economies, Baarsch et al. [6] observed that climate-induced losses cause between 10 % and 15 % of GDP per capita growth and that most African economies are poorly adapted to their current climatic conditions, thus affecting their financial stability. From the global perspective, Liu et al. [4] examined the impact of climate risk on financial stability from 2007 to 2019 in 53 countries, from different continents including about 12 African countries, and they found that Climate risk negatively affects financial stability. Brown et al. [40] observed that in sub-Saharan Africa drought is the most significant climate influence on GDP per capita growth and in some instances temperature and precipitation variability show significant effects in some cases.

1.3. The signing of the Paris agreement: climate risk and financial stability in Africa

The Paris Agreement signed at the 21st United Nations Climate Change Conference is an international treaty which expects countries to initiate or commit themselves to measures to solving challenges associated with climate change. As climate risk impacts the financial stability of countries, then commitments by governments, regulators and financial institutions in line with the Paris Agreement in improving or reducing the adverse impact of climate risk would influence their financial stability. Indeed, prior literature has asserted that the enactment of the Paris Agreement is a game changer for the handling of climate risk exposure [4,14–16], which would impact on countries financial stability. Gallas and Bouzgarrou, [41] recently examined the relationship between climate policy and the default risk associated with financial institutions in European Union nations from 2006 to 2022. They found that companies with higher CO2 emissions had increased credit risk following the Paris Agreement event, because of potential future climate regulatory changes, which would impact financial stability in the European region.

Although prior research has helped in the understanding of the impact of climate risk on financial stability [4,14,42], there is less focus on the African continent. African countries face peculiar economic challenges and have different governance systems as compared to other continents, therefore the impact of climate risk on the financial stability focusing on African countries who are faced with various economic challenges are needed. In the African context, although most of the African countries have signed the Paris Agreement, empirical analysis as to the impact of climate risk exposure on financial stability within the African continent following the enactment of the Paris Agreement has received less attention. Most African countries have signed the Paris Agreement and submitted their intended Nationally Determined Contributions, with the majority ratifying their Nationally Determined Contributions. In addition, most African countries are working towards transitioning to a low-carbon economy [28]. Therefore, the study adopts the conceptual framework in Fig. 2 and proposes the following hypothesis:

H1: The enactment of the Paris Climate Agreement has helped to mitigate the adverse impact of climate risk on the financial stability of African countries compared to the period before its enactment.

Figure 2: The proposed conceptual framework

1.4. National governance system

Prior research asserts that good governance, that is, Control of Corruption (COC), Government Effectiveness (GOE), Political Stability (POS), Regulatory Quality (RGQ) and Voice and Accountability enhance financial development, promote the financial stability of countries and in the case of climate risk exposure a good governance system would help mitigate or recover from the damages caused by climate risk exposure (e.g. [4,43]). In addition, prior studies assert that a stable political environment and an efficient administrative system help countries in the mitigation of climate risk casualties (e.g. [4]). Therefore, this study seeks to test the hypothesis that:

H2: The enhancement of the quality of the governance system of African countries can help to mitigate the impact of climate risk on their financial stability.

2. Data and methodology

2.1. Sample selection and data

This paper investigates the impact of climate risk on African country's financial stability before the enactment of the Paris Agreement (2010–2014) and during the enactment of the Paris Agreement (2015–2019). In addition, the paper examines the climate risk and African financial stability for the period (2010–2019). Furthermore, the paper explores the impact of financial development, competitive environment and national governance system on the climate risk and financial stability relationship focusing on African countries for the period (2010 to 2019). The period 2015–2019 is considered as during

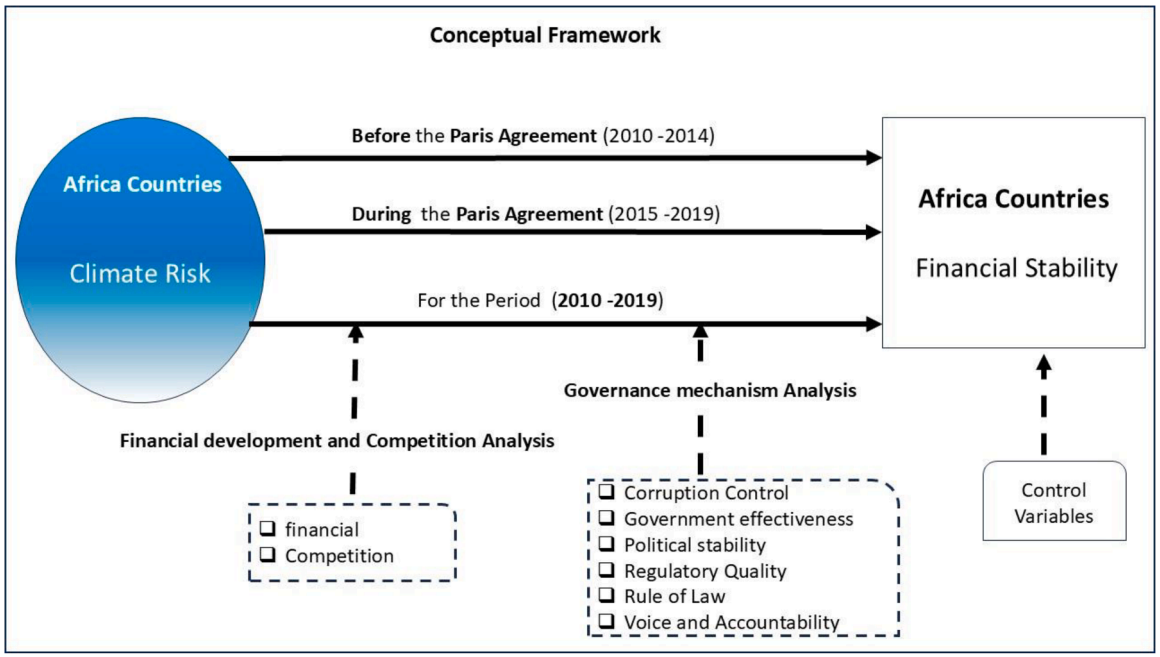

Fig. 2. The proposed conceptual framework.

the enactment of the Paris Agreement, following [4] while the period (2010–2014) is considered for comparison purposes. The study data is sourced from trustworthy sources of Germanwatch Firm organization and the World Bank database. The 32 African countries were selected based on the availability of data on climate risk and the availability of consistent and accurate data for other variables for the research. The data was processed using STATA 15 statistical software and data for the study can be accessed at: https://docs.google.com/spreadsheets/d/1NY7qnzCaoR2zF-TutFvjSXF5mc2Zu0s4/edit?usp=drive_link&ouid=101432304687853023972&rtpof=true&sd=true

Table 1 Sample Selection for the Study

2.2. Variable measurement

Following prior research [4,44], Zscore (ZSC) is considered a measurement of financial stability. The Z-score is a widely used metric to assess financial stability, particularly in the financial sectors. The Z score measures the distance from insolvency, showing the number of standard deviations a country's banking sector profits may fall before they become insolvent. Thus, a higher Z-score shows greater financial stability, and a lower score suggests otherwise, i.e. insolvency.

Climate Risk (CRI) is measured by the climate risk index sourced from the Germanwatch organization, following prior research [14]. The climate risk Index measures the extent by which the countries have been affected by weather-related loss events (storms, floods, heat waves etc.). Consistent with prior research [4,42] the climate risk index is multiplied by −1, therefore, a higher climate index score represents higher climate risk exposure. The CRI is a Global Climate Risk Index (CRI) provided by the Germanwatch organization which assesses countries' exposure to climate-related losses based on four indicators: that is deaths per 100, 000 people, the total fatalities, the total losses (PPP, USD) and the losses per GDP unit. The index score is a weighted average of these indicators, with lower scores suggesting higher climate risk exposure. The index provides a comprehensive measure of climate-related risks and impacts.

Table 1
Sample countries.

African Countries		
Algeria	Kenya	Nigeria
Angola	Lesotho	Rwanda
Burkina Faso	Libya	Senegal
Cameroon	Madagascar	South Africa
Cape Verde	Mali	Tanzania
Côte d'Ivoire	Mauritania	Togo
Democratic Republic of the Congo	Mauritius	Tunisia
Egypt	Morocco	Uganda
Eswatini	Mozambique	Zambia
Gabon	Namibia	Zimbabwe
Ghana	Niger	

Source(s): Table by author

In line with other studies on climate risk and financial stability [4,42], the study considers seven control variables, which can impact a country's financial stability, which is GDP per capita (GDP) this measures the total economic output of a country divided by its population. This measurement estimates the average standard of living and economic well-being of individuals within a country. GDP growth (GDG) measures the percentage change in a country's Gross Domestic Product (GDP) over a year. This measurement indicates the rate of economic expansion or contraction within a country. Inflation (INF) assesses the increase in the general price level of goods and services in an economy over time. INF reduces the purchasing power of money and can affect financial stability. Bank return on Assets (BOA) measures a country's bank's profitability in relation to its total assets. This measurement indicates how efficiently a country's banks are using its assets to generate profits. The ratio of bank deposits to GDP (BDP) measures the proportion of a country's economic output (GDP) that is held in its bank's deposits. This measurement provides an understanding of the financial depth and stability of an economy. The private credit to GDP ratio (PCP) measures the financial resources provided to the private sector by a country 's domestic money banks as a share of GDP. The measurement shows the level of financial development and access to credit in an economy. A higher PCP indicates greater financial intermediation and potential for economic growth and Bank concentration (CON) assesses the assets of the largest three banks as a percentage of total bank assets in a country. This measurement assesses the competition within the financial system of a country.

Hypothesis two following [4,45] governance system of: Control of Corruption (COC) measured as the extent to which a country's institutions, laws, and practices prevent, detect, and punish corruption;

Government Effectiveness (GOE) measured as the quality of public services, policy formulation, and implementation of policies by a government; Political Stability (POS) measures the perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism; Regulatory Quality (RGQ) measures the ability of a government to formulate and implement sound policies and regulations that promote the private sector development; and Voice and Accountability (VOA) measures the extent to which citizens can participate in selecting their government and hold them accountable is assessed by introducing two dummy variables High governance indicator (HGOI) and low governance indicator (LGOI) which are measured as a value of 1 when a country has a high and low governance system, respectively; otherwise, they are 0. Table 2 shows the description of the variables

Table 2: Description of variable

Table 2
Description of variable.

Variable	Description	Source
Z-score (ZSC)	(Z-score Country-level),	World Bank Global Financial Development Database (country-level)
Explanatory variable		
Climate Risk (CRI)	(Climate Risk Index multiply by −1), the higher the climate risk index score, the greater the climate risk of the country	Climate Risk Index released by Germanwatch
Bank Related Control Variables		
Bank return on Assets (BOA)	Banks' after-tax net income to yearly averaged total assets.	World Bank Global Financial Development Database
Private Credit to GDP ratio (PCP)	(Loan / Bank Deposit) multiply by (Bank Deposit/GDP): Private credit provided to the economy by Banks	World Bank Global Financial Development Database
Bank concentration (CON)	The assets of the largest three banks as a percentage of total bank assets in a country	World Bank Global Financial Development Database
Bank deposit to GDP (BDP)	The claims on the domestic real nonfinancial sector by deposit money banks as a share of GDP	World Bank Global Financial Development Database
Macroeconomic Control variables		
GDP per capita (GDP)	Log of a country's GDP per capita	World Bank World Development Indicators
GDP growth (GDG)	Percent changes in GDP	World Development Indicators
Inflation rate (INF)	Change in the consumer price index	World Bank World Development Indicators
Governance System: Control of Corruption (COC), Government Effectiveness (GOE), Political Stability (POS), Regulatory Quality (RGQ), Rule of Law (ROL) and Voice and Accountability (VOA)	HGOI and LGOI are 1 when a Country governance system has a high and low level of governance, respectively otherwise they are 0. Those above the median value of the sample is HGOI and those below are LGOI	World Bank Governance Indicators
Source(s): Table by author		

2.3. Research model

Considering prior studies on climate risk and financial stability [4, 42] , the study uses the model below to verify hypothesis 1, by running a panel data regression for the periods (2010–2014) , (2015–2019) and (2014–2019). The below model is considered as the benchmark regression model for testing hypothesis 1

$$ZSC_{it} = \beta_0 + \beta_1 CRI_{it} + \beta_2 CON_{it} + \beta_3 PCP_{it} + \beta_4 BDP_{it} + \beta_5 BOA_{it} + \beta_6 GDG_{it} + \beta_7 GDP_{it} + \beta_8 INF_{it} + \in_{it}$$

The subscripts i and t represent countries and years, respectively. ZSC_{it} is financial stability. The primary variable of interest in these models is CRI_{it} which is countries climate risk index in year t. ε_{it} is the error term and other variables in the models are the control variables defined in Table 2.

The fixed effect and random effect models are used for the study. The main variable of interest the CRI results is consistent under the models. The untabulated results of the Breusch Pagan test and the Hausman test conclude that the fixed effect model is to be used for the study. Therefore, the fixed effect results are used as the benchmark, while the random effect is just reported.

The Fixed Effect estimation as a statistical technique helps to analyse panel data and accounts for individual-specific effects that are constant over time. It involves controlling for unobserved heterogeneity and captures time-invariant differences between entities (i.e. countries). It also analyses within-unit variations and focuses on changes within each entity or country over time [46]. In the context of the study the relevance of the fixed effect estimation is that it controls for country-specific effects: allowing the study to isolate the impact of climate risk on the financial stability of African countries. It also accounts for time-invariant factors: for example, such as geographical location. Finally, providing more accurate estimations by controlling for individual-specific effects reduces bias and provides more reliable results.

As a robustness check panel corrected standard errors Model and Driscoll-Kraay standard errors Model, catering for cross-sectional dependence is used. In addition, the two-step dynamic system GMM model considering endogeneity issues and other robust analyses are used to verify hypothesis 1. Also, heterogeneity analyses are carried out.

In relation to hypothesis 2, following [4], the study adopts the below model to verify it. The benchmark panel regression model for testing hypothesis 2 is:

$$ZSC_{it} = \beta_0 + \beta_1 (CRI * HGOI)_{it} + \beta_2 (CRI * LGOI)_{it} + \beta_3 CON_{it} + \beta_4 PCP_{it} + \beta_5 BDP_{it} + \beta_6 BOA_{it} + \beta_7 GDG_{it} + \beta_8 GDP_{it} + \beta_9 INF_{it} + \in_{it}$$

(CRI* HGOI) and (CRI* LGOI) represent the interaction of climate risk with high and low governance indicators respectively. The other elements are as defined previously above. The rational for using the median-based categorization is to mitigate the influence of outliers, enhance the robustness and interpretability of our classification, and create more balanced groups [47].

The untabulated results of the Breusch Pagan test and the Hausman test conclude that the fixed effect model is to be used in testing hypothesis 2. The two-step dynamic system GMM model is used for robust analysis.

3. Empirical results

3.1. Descriptive statistics, correlation matrix and univariate tests

Table 3 shows the descriptive statistics of the main variables. For the full period, the maximum climate risk exposure is −2.67 while the minimum climate risk exposure is −126.17, this indicates a greater degree of differences among African country's climate risk exposure considering the period 2010 to 2019. Their financial stability has a mean value of 17.625 % with a standard deviation of 8.532 for the period 2010

Table 3
Descriptive statistics.

Variable	ZSC	CRI	CON	PCP	BDP	BOA	GDG	GDP	INF
Full Period (2010–2019)									
Mean	17.625	−78.795	0.649	0.289	0.387	0.017	0.044	11.909	0.06
Std. Dev.	8.532	31.248	0.178	0.252	0.323	0.01	0.068	1.974	0.149
Min	4.268	−126.17	0.291	0.038	0.071	−0.032	−0.503	6.844	−0.032
Max	66.634	−2.67	1	1.734	2.421	0.045	0.868	15.393	2.553
Obs	320	320	320	320	320	320	320	320	320
Before the Paris Agreement (2010–2014)									
Mean	17.845	−78.175	0.686	0.294	0.369	0.018	0.049	11.746	0.051
Std. Dev.	9.24	29.097	0.186	0.291	0.291	0.01	0.089	2.019	0.04
Min	4.268	−126.17	0.325	0.038	0.071	−0.003	−0.503	6.844	−0.024
Max	66.634	−15.67	1	1.734	1.544	0.045	0.868	15.393	0.166
Obs	160	160	160	160	160	160	160	160	160
During the Paris Agreement (2015–2019)									
Mean	17.405	−79.416	0.611	0.285	0.405	0.016	0.038	12.073	0.069
Std. Dev.	7.782	33.341	0.162	0.207	0.352	0.01	0.035	1.921	0.207
Min	5.128	−125	0.291	0.054	0.091	−0.032	−0.063	7.252	−0.032
Max	44.514	−2.67	1	1.027	2.421	0.04	0.325	15.299	2.553
Obs	160	160	160	160	160	160	160	160	160
Source(s): Table by author									

to 2019. Before the enactment of the Paris Agreement, the countries had a financial stability mean value of 17.85 % compared to 17.405 % during the enactment period. The mean value of climate risk exposure before the Paris Agreement enactment was −78.175 compared to −79.416 during the Paris Agreement enactment. For the control variables for the period 2010 to 2019, before and during the Paris Agreement enactment, their standard deviations do not disperse much from their mean values.

The T-test and Mann -Whitney U test in Table 4 confirmed no significant difference between African countries' climate risk exposure and their financial stability before and during the enactment of the Paris Agreement. The correlation among the variables is presented in Table 5. The results show that CRI is negatively related to ZSC at the 10 % level, which supports the literature that climate risk negatively impacts financial stability. PCP and BDP recorded the highest correlation coefficient of 0.744, therefore, per the theory of statistics multicollinearity is not present. Furthermore, in untabulated results, the Variance Inflation Factor test of the variables were below 10, which indicates that there is no multicorreliarity issue with our models.

Table 3 Descriptive Statistics
Table 4 Univariate test
Table 5 Correlation Matrix

3.2. Regression results

The estimation coefficients of climate risk in Table 6 for both the fixed effect and random effect model before the enactment of the Paris Agreement columns 1 and 2 are insignificant. Also, during the Paris Agreement enactment, the estimation coefficients of climate risk in columns 3 and 4 are insignificant. This suggests that before and after the Pris Agreement enactment, climate risk has no impact on the financial stability of African countries, which does not support hypothesis 1. This is inconsistent with prior research that concluded that the enactment of the Paris Agreement would reduce the adverse impact of climate risk exposure on financial stability [4,14–16]. Furthermore, considering the whole period of study, columns 5 and 6 also confirm that climate risk has no significant impact on the financial stability of African countries considering the enactment of the Paris Agreement.

Table 4
Univariate test.

	Before PAG (2010–2014)	**During PAG (2015–2019)**	**T-test**	**Mann-Whitney U Test**
Variable	Mean (median)	Mean (median)	(*P*-Value)	(*P*-Value)
ZSC	17.845 (16.354)	17.405 (16.482)	0.6452	0.9460
CRI	−78.175 (−81.67)	−79.416 (−79)	0.7230	0.4837

Notes: ***, ** and * indicate 1 %,5 % and 10 % significance levels. PAG represents Paris Agreement
Source(s): Table by author

For the control variables focusing on the fixed effect models. Columns 1,3 and 5 in Table 6 confirm that GDG that is growth in GDP has a negative impact on African country's financial stability before, during the enactment of the Paris Agreement and also for the whole period of study, that is (β= 138.32, β=83.847 and β=109.028 respectively), this is consistent with the findings of Liu et al. [4] who came to the same conclusion from the international perspective. The African case could also be attributed to the fact that most African governments do intervene in resource allocation within their financial system resulting in the negative impact of their GDG on their financial stability. Reasonably columns 1,3 and 5 in Table 6 show that African banks' return on assets (BOA) positively impacts their financial stability before, during the enactment of the Paris Agreement and for the whole period of study that is (β= 138.32, β=83.847 and β=109.028 respectively), which is consistent with the international perspective observed by Liu et al. [4] and Lin and Yang [48] observation in East Asian markets. Although GDP per capita was insignificant before the enactment of the Paris Agreement, it has positive estimate coefficients (β= 2.077 and β=1.795 respectively), during the Paris Agreement enactment and for the whole period of study respectively as reported in columns 3 and 5 in Table 6. The positive effect is consistent with Liu et al. [4] observation from the international perspective that an increase in GDP per capita enhances financial stability. Surprisingly, inflation (INF) positively impacts financial stability before the enactment of the Paris Agreement with an estimated coefficient of (β= 14.983) in column 1 in Table 6, however, during the Paris Agreement enactment it has a negative impact on financial stability with an estimated coefficient of (β= 1.794) in column 2 in Table 6.

Contrary to Liu et al. [4], who observed that from an international perspective, domestic credit to the private sector has a detrimental effect on financial stability, the findings for African countries are different. Column 1 in Table 6 shows that PCP has estimated positive coefficients of (β=13.699) before the Paris Agreement enactment, however, it had no significant impact during the Paris Agreement enactment in column 3 in Table 6. But consideration of the whole period, column 5 in Table 6 shows that PCP has estimated positive coefficients of (β=16.159). The plausible reason could be the gradual embracing of fintech within African countries' financial systems having reduced the rate of default on loans. Also, contrarily to Liu et al. [4] observation that the ratio of bank

Table 5
Pearson correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) ZSC	1.000								
(2) CRI	−0.206*	1.000							
(3) CON	0.098*	−0.019	1.000						
(4) PCP	0.369*	−0.135*	−0.019	1.000					
(5) BDP	0.435*	−0.241*	0.115*	0.744*	1.000				
(6) BOA	−0.084	0.206*	−0.010	−0.243*	−0.291*	1.000			
(7) GDG	−0.147*	−0.059	−0.084	−0.120*	−0.160*	0.069	1.000		
(8) GDP	−0.197*	0.025	−0.004	−0.217*	−0.306*	−0.097*	0.025	1.000	
(9) INF	−0.076	0.158*	−0.086	−0.088	0.010	0.187*	−0.099*	−0.122*	1.000

Notes: ***, ** and * indicate 1 %,5 % and 10 % significance levels.
Source(s): Table by author

deposits has no significant impact on financial stability, columns 1,3,5 in Table 6 shows that the observation for African countries BDP has estimated negative coefficients of (β=18.142, β=4.6 and β= 19.764 respectively) for before, during the Paris Agreement enactment and for the whole study period respectively. This highlights that although deposits within the financial system are good for bank stability, in Africa's case it can be argued that funds are needed for the private sector to enhance development within their financial system. This confirms that excessive deposit within the banking sector stifles the development of the private sector negatively impacting African countries financial stability. Before the Paris Agreement bank concentration (CON) reported in column 1 in Table 6 negatively impacted financial stability with an estimated negative coefficient of (β=6.256), however, during the enactment of the Paris Agreement it had no impact. But consideration of the whole study period column 5 shows that CON positively impacts African country's bank stability with an estimated coefficient of (B = 3.683), which could be the competitive environment within their financial system brought about by foreign investment in their banking system and enhanced mechanism in reducing the default of loans within their banking system coupled with the gradually embracing of fintech and digitalization.

Concerning hypothesis two the fixed effect models in Table 7 show that climate risk has an insignificant impact on the financial stability of African countries whether with higher or lower governance quality systems. The finding that higher quality governance system interaction with climate risk (CRI* HGOI) does not have any significant impact on African countries' financial stability, is consistent with the findings of Liu et al. [4] from the international perspective, which partially support hypothesis two. However, the findings that the interaction of the poor-quality governance system of African countries with their climate risk (CRI* LGOI) does not have any significant impact on their financial stability is inconsistent with the findings of Liu et al. [4] who observed that from the international perspective, poor quality governance system interacting with climate risk reduce the financial stability of countries.

From the African perspective, the insignificant impact of the interaction of climate risk with high or low-quality governance systems could be attributed to the many peculiar challenges faced by African countries generally concerning Poverty, Political instability, Poor infrastructure, corruption, health issues, education deficits, unemployment, Climate change challenges, food insecurity, gender inequality, armed conflicts, migration and displacement, water scarcity, inadequate healthcare facilities and economic dependency and others challenges overshadowing the impact of high or low governance quality interacting with climate risk and impacting on financial stability.

Table 6 Regression Results

Table 7: Governance mechanism Analysis

3.3. Robustness results

Several robustness analyses were carried out to validate hypothesis 1. First, panel-corrected standard error regressions were estimated using the benchmark regression. The Panel-Corrected Standard Error Regressions which address heteroskedasticity by accounting for non-constant variance across panels and correcting for contemporaneous correlation by adjusting for correlation between panels [49], is used to validate the main findings. Concerning the study, it estimates robust standard errors which makes the estimations more accurate and reliable and helps improve inference by catering for heteroskedasticity and contemporaneous correlation. Columns 7, 9 and 11 in Table 6 show the regression results. Second, the Driscoll-Kraay standard errors model as a statistical estimation technique which addresses heteroskedasticity by accounting for non-constant variance and correcting for autocorrelation by adjusting for serial correlation within panels and accounting for cross-sectional dependence by handling correlation between panels [50], is used as additional estimation to validate the main findings of the study. In the context of the study, its relevance is that it provides robust standard errors making the estimates more accurate and reliable and it also improves inference by accounting for heteroskedasticity, autocorrelation, and cross-sectional dependence. Table 6 columns 8,10 and 12 show the Driscoll- Kraay regression results. Third, following Liu et.al [4] we used the natural log of ZSC as a measure of financial stability, therefore in the benchmark regression model, ZSC is replaced with its natural log value (log ZSC). Columns 13,14, 17,18,21 and 22 in Table 8 show the fixed effect and the random effect regression results. Fourth, using the natural log of the ZSC (log ZSC) as a financial stability panel corrected standard error regressions were estimated. Columns 15,19 and 23 in Table 8 show the panel corrected standard error regressions replacing ZSC with its natural log value. Fifth, also with the natural log value of ZSC the Driscoll-Kraay regressions were estimated. Columns 16, 20 and 24 in Table 8 show the regression results of Driscoll-Kraay with the natural log value of ZSC. Sixth, considering that financial stability and climate risk there would be endogeneity issues, the first-order lag term of financial stability was introduced into the model.

The Two-Step Dynamic System GMM model estimation as a statistical technique used to analyse dynamic panel data, is also used to validate the findings of the study. It addresses endogeneity by accounting for potential correlations between the explanatory variables and the error terms. It also captures the dynamic relationships by estimating the impact of lagged dependent variables on the estimations. The GMM estimation uses Instrumenting variables which help to address endogeneity [51]. In the context of the study, the relevance of the GMM validating the findings is that it addresses potential endogeneity between climate risk and the financial stability of African countries. The model also helps to explain the dynamic relationships between African country's financial stability and its determinants. The model provides robust estimation by using internal instruments and accounting for heteroskedasticity. Table 9 columns 1,2 and 3 show the System – GMM regression. Seventh, the natural log of ZSC is used as a measure of financial stability and in addressing endogeneity issues the first-order lag term of the natural log of ZSC is introduced into the model. Table 9 columns 4,5 and 6 show the system-GMM regression results. These results confirm that indeed climate risk did not impact African countries before, during the Patis Agreement enactment and for the whole study period.

Table 6
Regression results.

	Before PAG (2010–2014)		During PAG (2015–2019)		Full Period (2010–2019)		Before PAG (2010–2014)		During PAG (2015–2019)		Full Period (2010–2019)	
	Baseline Regression Results						Robust Analysis					
	1	2	3	4	5	6	7	8	9	10	11	12
	FE	RE	FE	RE	FE	RE	PCSE	DKSE	PCSE	DKSE	PCSE	DKSE
Variable	ZSC	ZSC	ZSC	ZSC	ZSC	ZSC	ZSC	ZSC	ZSC	ZSC	ZSC	ZSC
CRI	−0.003	−0.004	0.005	0.003	0.002	−0.000	−0.001	−0.003	−0.004	0.005	−0.003	0.002
	(0.009)	(0.009)	(0.004)	(0.005)	(0.006)	(0.006)	(0.007)	(0.005)	(0.008)	(0.003)	(0.006)	(0.002)
CON	−6.256*	−2.716	1.236	2.972	3.683**	3.054	0.109	−6.256**	2.251*	1.236*	0.827	3.683
	(3.619)	(3.513)	(3.638)	(3.487)	(1.820)	(1.888)	(2.410)	(1.729)	(1.245)	(0.527)	(1.772)	(2.357)
PCP	13.699***	8.526**	2.759	3.683	16.159***	15.220***	−6.304	13.699	14.232***	2.759	2.602	16.159***
	(3.651)	(3.814)	(3.560)	(3.421)	(1.661)	(1.776)	(9.266)	(6.623)	(3.750)	(3.125)	(5.070)	(2.424)
BDP	−18.142***	−10.858***	−4.600***	−4.348***	−19.764***	−18.021***	10.699	−18.142*	−0.827	−4.600**	−0.081	−19.764***
	(3.834)	(3.998)	(1.528)	(1.559)	(1.374)	(1.467)	(11.348)	(7.799)	(3.354)	(1.276)	(5.900)	(2.951)
BOA	138.321***	112.375***	83.847***	89.736***	109.028***	101.866***	88.650**	138.321***	106.344***	83.847**	98.076***	109.028***
	(32.930)	(36.395)	(16.856)	(17.832)	(21.233)	(22.998)	(36.084)	(14.664)	(22.780)	(27.006)	(17.110)	(21.782)
GDG	−11.260***	−8.802***	−7.026*	−6.606*	−12.909***	−12.651***	−4.189	−11.260*	0.504	−7.026**	−8.082	−12.909
	(2.571)	(2.870)	(3.553)	(3.780)	(2.051)	(2.243)	(8.803)	(4.411)	(8.537)	(1.633)	(5.463)	(7.146)
GDP	−1.946	−0.948	2.077***	0.542	1.795***	0.293	−0.539**	−1.946*	−0.352*	2.077**	−0.674***	1.795**
	(1.477)	(0.634)	(0.741)	(0.518)	(0.578)	(0.446)	(0.234)	(0.822)	(0.185)	(0.597)	(0.211)	(0.583)
INF	14.983**	15.581*	−1.794**	−0.614	−1.356	−0.160	5.793	14.983*	0.263	−1.794**	−0.628	−1.356*
	(7.376)	(8.155)	(0.769)	(0.699)	(1.086)	(1.126)	(12.404)	(5.587)	(1.574)	(0.419)	(1.729)	(0.623)
_cons	44.773**	29.693***	−7.935	8.795	−4.205	13.517**	20.060***	44.773***	14.589***	−7.935	23.019***	−4.205
	(18.188)	(8.221)	(8.941)	(6.662)	(7.332)	(5.873)	(4.516)	(9.494)	(3.039)	(6.646)	(3.481)	(8.250)
Observations	160	160	160	160	320	320	160	160	160	160	320	320
R^2	0.3413		0.3470		0.5027		0.455	0.3413	0.5620	0.3470	0.4138	0.5027
P_Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: ***, ** and * indicate 1 %,5 % and 10 % significance levels. Standard errors are in parentheses. FE, RE, PCSE and DKSE represent Fixed Effect Model, Random Effect Model, Panels Corrected standard errors Model and Driscoll-Kraay standard errors Model respectively.

Source(s): Table by author

Table 7
Governance mechanism analysis.

	COC		GOE		POS		RGQ		ROL		VOA	
	FE	GMM	FE	GMM	FE	GMM	FE	GMM	FE	GMM	FE	GMM
L.ZSC		0.535**		0.532**		0.547**		0.542**		0.527**		0.607**
		(0.211)		(0.246)		(0.198)		(0.205)		(0.204)		(0.226)
CRI* HGOI	0.005	0.001	0.002	0.001	0.004	0.012	0.005	−0.001	−0.000	0.003	0.006	0.000
	(0.007)	(0.015)	(0.006)	(0.007)	(0.007)	(0.015)	(0.006)	(0.013)	(0.006)	(0.016)	(0.007)	(0.012)
CRI* LGOI	−0.000	−0.001	0.003	−0.019	0.001	−0.009	−0.001	0.002	0.005	−0.002	−0.003	−0.007
	(0.006)	(0.014)	(0.007)	(0.017)	(0.007)	(0.014)	(0.007)	(0.016)	(0.007)	(0.012)	(0.007)	(0.015)
CON	3.680**	−7.063	3.682**	−7.265	3.714**	−6.613	3.601**	−7.414	3.572*	−6.057	3.418*	−9.174
	(1.821)	(6.595)	(1.823)	(5.466)	(1.824)	(6.787)	(1.821)	(6.865)	(1.825)	(6.738)	(1.831)	(7.951)
PCP	16.190***	1.933	16.157***	1.344	16.230***	2.151	16.281***	0.516	16.184***	1.314	16.354***	1.883
	(1.662)	(8.848)	(1.663)	(7.374)	(1.671)	(6.213)	(1.664)	(8.687)	(1.662)	(8.567)	(1.667)	(8.069)
BDP	−19.783***	1.832	−19.761***	3.251	−19.852***	2.281	−19.891***	2.114	−19.807***	3.007	−19.891***	1.586
	(1.374)	(5.752)	(1.376)	(5.126)	(1.390)	(3.370)	(1.378)	(5.580)	(1.375)	(5.360)	(1.376)	(5.334)
BOA	108.942***	11.224	108.997***	17.117	109.603***	32.052	109.694***	7.454	109.791***	17.992	111.510***	10.188
	(21.245)	(61.744)	(21.270)	(56.858)	(21.305)	(60.226)	(21.234)	(63.469)	(21.260)	(67.999)	(21.315)	(51.796)
GDG	−12.936***	−0.234	−12.896***	−0.909	−12.962***	−4.549	−13.067***	0.203	−12.877***	1.039	−13.162***	1.776
	(2.052)	(11.075)	(2.055)	(13.486)	(2.057)	(10.806)	(2.055)	(12.096)	(2.052)	(11.917)	(2.060)	(9.369)
GDP	1.786***	0.186	1.801***	0.307	1.762***	−0.004	1.689***	0.217	1.742***	0.191	1.841***	0.252
	(0.579)	(0.329)	(0.580)	(0.348)	(0.584)	(0.311)	(0.586)	(0.369)	(0.582)	(0.308)	(0.579)	(0.265)
INF	−1.304	−0.185	−1.377	0.193	−1.305	−0.425	−1.206	−0.167	−1.373	−0.260	−1.311	0.229
	(1.089)	(1.334)	(1.092)	(1.135)	(1.094)	(1.161)	(1.094)	(1.308)	(1.087)	(1.313)	(1.086)	(1.232)
_cons	−4.073	7.340	−4.270	4.440	−3.828	8.735	−2.923	7.278	−3.507	6.578	−4.657	6.246
	(7.338)	(6.848)	(7.351)	(6.070)	(7.393)	(6.509)	(7.421)	(7.336)	(7.379)	(6.673)	(7.336)	(7.242)
Observations	320	146	320	146	320	146	320	146	320	146	320	146
R-squared	0.504		0.503		0.503		0.505		0.504		0.505	
F Statistics		358.96***		638.69***		689.50 ***		478.11 ***		342.77***		508.82***
Groups/Instruments		21/19		21/19		21/19		21/19		21/19		21/19
A-Bond AR (1) test		0.020		0.026		0.011		0.018		0.016		0.015
A-Bond AR (2) test		0.646		0.628		0.847		0.587		0.575		0.575
Sargan test		0.143		0.081		0.325		0.138		0.147		0.058
Hansen test		0.462		0.513		0.398		0.459		0.524		0.428

*Notes: *** $p<.01$, ** $p<.05$, * $p<.1$, indicate significance at the 1 %,5 % and 10 % levels respectively. Robust standard errors are in parentheses. P-Value reported for A-Bond AR (1) and AR (2), Sargan, and Hansen test statistics. FE represents Fixed Effect Model.*

Source(s): Table by author

Table 8
Additional robust regression analysis.

Variable: log ZSC	Before PAG (2010–2015)				During PAG (2016–2019)				Full Period (2010–2019)			
	13	14	15	16	17	18	19	20	21	22	23	24
	FE	RE	PCSE	DKSE	FE	RE	PCSE	DKSE	FE	RE	PCSE	DKSE
CRI	0.000	−0.000	−0.000	0.000	0.000	0.000	−0.000	0.000	0.000	0.000	−0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CON	−0.315**	−0.268*	−0.112	−0.315*	0.229	0.271	0.142**	0.229	0.141*	0.115	0.014	0.141
	(0.143)	(0.142)	(0.105)	(0.122)	(0.251)	(0.231)	(0.069)	(0.108)	(0.080)	(0.083)	(0.090)	(0.093)
PCP	0.325**	0.255*	−0.231	0.325**	−0.042	0.110	0.740***	−0.042	0.449***	0.438***	0.188	0.449***
	(0.144)	(0.151)	(0.338)	(0.115)	(0.245)	(0.227)	(0.224)	(0.130)	(0.073)	(0.077)	(0.197)	(0.058)
BDP	−0.440***	−0.317**	0.602	−0.440**	−0.177*	−0.160	0.066	−0.177*	−0.561***	−0.523***	0.031	−0.561***
	(0.151)	(0.158)	(0.404)	(0.148)	(0.105)	(0.105)	(0.194)	(0.068)	(0.061)	(0.064)	(0.214)	(0.068)
BOA	9.777***	9.315***	7.258***	9.777***	7.935***	8.285***	9.862***	7.935*	8.694***	8.524***	8.733***	8.694***
	(1.297)	(1.405)	(2.088)	(1.195)	(1.161)	(1.222)	(1.911)	(3.063)	(0.937)	(0.991)	(1.186)	(1.956)
GDG	−0.358***	−0.311***	−0.034	−0.358**	−0.463*	−0.414	0.012	−0.463**	−0.426***	−0.423***	−0.203	−0.426**
	(0.101)	(0.111)	(0.323)	(0.121)	(0.245)	(0.259)	(0.513)	(0.127)	(0.091)	(0.096)	(0.187)	(0.174)
GDP	0.035	0.012	0.020**	0.035	0.117**	0.045	0.020*	0.117*	0.112***	0.065***	0.010	0.112***
	(0.058)	(0.032)	(0.010)	(0.029)	(0.051)	(0.032)	(0.012)	(0.043)	(0.026)	(0.022)	(0.011)	(0.015)
INF	0.256	0.233	−0.171	0.256	−0.044	0.013	0.044	−0.044	−0.028	0.008	0.000	−0.028
	(0.291)	(0.315)	(0.650)	(0.181)	(0.053)	(0.047)	(0.129)	(0.031)	(0.048)	(0.049)	(0.118)	(0.020)
_cons	2.475***	2.687***	2.307***	2.475***	1.209*	1.982***	2.016***	1.209*	1.323***	1.876***	2.421***	1.323***
	(0.716)	(0.407)	(0.214)	(0.383)	(0.616)	(0.417)	(0.191)	(0.491)	(0.324)	(0.284)	(0.171)	(0.202)
Observations	160	160	160	160	160	160	160	160	320	320	320	320
R^2	0.4176		0.8325	0.4176	0.4179		0.8808	0.4179	0.4410		0.8249	0.4477
P_Value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: ***, ** and * indicate 1 %,5 % and 10 % significance levels. Standard errors are in parentheses. FE, RE, PCSE and DKSE represent Fixed Effect Model, Random Effect Model, Panels Corrected standard errors Model and Driscoll-Kraay standard errors Model respectively.
Source(s): Table by author

For hypothesis two, the robust analysis was carried out using the system -GMM regression estimation. The system GMM regression results in Table 7 validate the findings that neither the interaction of higher quality governance system with climate risk (CRI*HGOI) nor the interaction of a poor-quality governance system with climate risk (CRI*LGOI) has any significant impact on the financial stability of African countries.

Table 8 Additional Robust Regression Analysis
Table 9 Other Robust Analysis

3.4. Heterogeneity analysis: financial development and competitive environment

Since the development of the financial sector of African countries varies among the countries, the study explores whether climate risk impacts financially developed and financially restricted African countries differently. Therefore, following Liu et al. [4], the study focuses on the whole period of study and uses the ratio of private credit to GDP as a base to divide the sample into two, by 1) countries having a ratio above and equal to the median value of the sample countries are considered as financial developed and 2) those below the median are considered as financial restricted countries. Table 10 column 1 shows that climate risk has no significant impact on the financial stability of financially developed countries, which is consistent with the findings of Liu et al. [4], however inconsistent with their findings is that financially restricted African countries also show no significant impact of climate risk on their financial stability as reported in Table 10, column 3. From the international perspective, Liu et al. [4] found that climate risk does reduce the financial stability of financially restricted countries. The inconsistent results could be attributed to the numerous challenges facing African countries in general. Columns 2 and 4 in Table 10 using the system GMM validate the findings.

The study also acknowledges the fact that the degree of competition among African countries may have an impact on their climate risk exposure and their financial stability relationship, as prior research has confirmed the impact of competition on financial stability [4,52]. Therefore, for the whole period of study using bank concentration as a base to divide the sample into two, 1) countries with low competition that have having ratio above and equal to the median value of the sample countries and 2) those below the median are considered high competition. Table 10 column 5 shows that climate risk has no significant impact on the financial stability of AFC with a high degree of competition, which is inconsistent with the findings of Liu et al. [4], from the international perspective. However, Table 10 column 7 reports that climate risk has no significant impact on the financial stability of AFC with a low degree of competition, which is consistent with the findings of liu et al. [4] from the international perspective. The irrelevance of the degree of competition on the CRI exposure and financial stability of AFC could also be attributed to the numerous challenges facing African countries in general. Columns 6 and 8 in Table 10 using the system GMM validate the findings.

Table 10: Financial development and Competition Analysis

4. Discussion

The results show that climate risk has no insignificant impact on African country's financial stability before and after the enactment of the Paris Agreement and for the study period. In addition, there is no impact of their financial development and competitive environment and their national governance system on the climate risk and financial stability relationship. The study although was grounded in the sustainability transition theory, the empirical results did not align with its core assumptions. This discrepancy could be attributed to the unique challenges faced by African countries, including their economic conditions, governance systems, and other contextual factors. These findings are consistent with previous studies on African countries, which they have

Table 9
Other robust analysis.

Variable	Using ZSC for GMM Model			Using log of ZSC for GMM Model		
	Before	During	Full Period	Before	During	Full Period
	1	2	3	4	5	6
	ZSC	ZSC	ZSC	Log ZSC	Log. ZSC	Log. ZSC
L.ZSC	0.787***	0.751***	0.777***			
	(0.087)	(0.146)	(0.165)			
L. Log ZSC				0.849***	0.569**	0.420
				(0.126)	(0.226)	(0.297)
CRI	−0.003	−0.016	−0.009	−0.000	−0.001	−0.001
	(0.006)	(0.009)	(0.006)	(0.000)	(0.001)	(0.001)
CON	−0.498	1.413	−0.200	−0.001	0.077	0.029
	(0.904)	(1.586)	(0.846)	(0.063)	(0.138)	(0.165)
PCP	−1.429	3.068	1.026	0.011	0.216	0.222
	(1.579)	(2.628)	(0.955)	(0.090)	(0.202)	(0.233)
BDP	3.032	−0.038	0.853	0.058	0.102	0.271
	(2.569)	(1.119)	(1.997)	(0.165)	(0.122)	(0.219)
BOA	39.824	74.346*	53.601**	1.786	8.503*	8.075
	(24.303)	(42.475)	(21.428)	(1.639)	(4.607)	(5.312)
GDG	−14.127***	3.025	−12.996***	−0.282***	0.026	−0.461
	(1.463)	(6.143)	(1.160)	(0.073)	(0.532)	(0.402)
GDP	−0.121	0.048	−0.014	−0.004	0.015	0.017
	(0.100)	(0.195)	(0.139)	(0.010)	(0.022)	(0.026)
INF	2.891	0.006	−0.811	0.568	−0.041	−0.120
	(7.117)	(0.812)	(0.905)	(0.460)	(0.110)	(0.178)
_cons	4.366*	−0.591	2.504	0.387	0.638	1.054
	(2.343)	(3.191)	(2.796)	(0.325)	(0.474)	(0.754)
Observations	128	160	288	128	160	288
F Statistics	1489.88***	1188.24 ***	2347.30***	6674.27***	2875.42***	1125.25***
Groups/Instruments	32/14	32/18	32/18	32/14	32/18	32/18
A-Bond AR (1) test	0.011	0.051	0.022	0.033	0.037	0.145
A-Bond AR (2) test	0.132	0.157	0.165	0.288	0.328	0.742
Sargan test	0.014	0.001	0.000	0.012	0.020	0.035
Hansen test	0.675	0.306	0.339	0.313	0.245	0.256

*Notes: *** p<.01, ** p<.05, * p<.1, indicate significance at the 1 %,5 % and 10 % levels respectively. Robust standard errors are in parentheses. P-Value reported for A-Bond AR (1) and AR (2), Sargan, and Hansen test statistics*
Source(s): Table by author

Table 10
Financial development and competition analysis.

	Financially developed		Financial restricted		High competition		Low competition	
	1	2	3	4	5	6	7	8
	FE	GMM	FE	GMM	FE	GMM	FE	GMM
L.ZSC		1.059***		0.825***		0.918***		0.541**
		(0.128)		(0.042)		(0.087)		(0.211)
CRI	0.001	−0.002	0.004	−0.002	0.013	−0.003	−0.003	−0.000
	(0.007)	(0.010)	(0.006)	(0.005)	(0.011)	(0.005)	(0.004)	(0.014)
CON	1.991	−0.519	−0.531	0.961	3.350	−1.553	7.216**	−7.487
	(2.757)	(2.856)	(1.550)	(1.135)	(4.272)	(2.241)	(2.958)	(6.755)
PCP	6.049***	−0.169	0.432	3.256	20.577***	0.916	1.454	1.094
	(2.095)	(0.671)	(7.579)	(6.139)	(2.382)	(1.247)	(3.040)	(8.136)
BDP	−8.590***	−2.031	−20.565***	0.349	−24.013***	−0.432	−9.137***	1.812
	(2.055)	(1.656)	(4.599)	(1.687)	(2.082)	(2.501)	(2.973)	(5.256)
BOA	137.144***	31.759	92.542***	69.017***	94.410**	51.490	128.883***	9.215
	(29.557)	(55.334)	(18.285)	(23.704)	(37.482)	(38.005)	(17.814)	(62.135)
GDG	−47.815***	−7.754	−2.009	−6.987**	−14.214***	−13.993***	−11.465***	−0.455
	(3.630)	(7.494)	(1.989)	(2.884)	(2.761)	(0.885)	(3.995)	(11.258)
GDP	2.142**	0.065	1.579***	0.243*	1.801	−0.045	2.224***	0.200
	(0.950)	(0.289)	(0.478)	(0.137)	(1.501)	(0.112)	(0.412)	(0.348)
INF	16.647***	6.560	−1.716**	−0.153	23.609***	1.386	−2.615***	−0.195
	(5.498)	(6.786)	(0.839)	(0.407)	(8.304)	(10.646)	(0.640)	(1.324)
_cons	−4.652	−0.770	−1.170	−2.631	−1.023	2.487	−13.782**	7.472
	(11.469)	(5.859)	(6.161)	(1.984)	(19.570)	(2.500)	(5.698)	(7.040)
Observations	160	147	160	141	160	142	160	146
R-squared	0.704		0.310		0.587		0.440	
F Statistics		4297.16 ***		6417.74***		5045.09 ***		410.58 ***
Groups/Instruments		20/18		21/18		22/18		21/18
A-Bond AR (1) test		0.045		0.013		0.033		0.020
A-Bond AR (2) test		0.678		0.210		0.370		0.626
Sargan test		0.024		0.003		0.001		0.138
Hansen test		0.227		0.195		0.538		0.449

*Notes: *** p<.01, ** p<.05, * p<.1, indicate significance at the 1 %,5 % and 10 % levels respectively. Robust standard errors are in parentheses. P-Value reported for A-Bond AR (1) and AR (2), Sargan, and Hansen test statistics. FE represents Fixed Effect Model*
Source(s): Table by author

also highlighted (e.g., [53]). The next section elaborates on the main reasons and other factors that may have accounted for this outcome.

These findings could be attributed to the main reasons that: African countries face barriers in implementing the Paris Agreement requirements. These barriers are not limited to funding, institutional weaknesses, inadequate legal framework, lack of intersectoral coordination and political challenges. For funding climate risk mitigation measures African countries have limited financial resources by depending on external funding and also transitioning to low-carbon economies poses a high cost to them. This is consistent with Mungai et al. [53] findings that sub-Saharan African countries face significant challenges of funding, policy and institutional barriers in climate risk mitigation in terms of financing renewable energy. This also collaborates with Adenle et al. [54] finding that African countries face a lack of institutional capacity in implementing climate risk mitigation projects. This also gives credence to, recently the International Monetary Fund emphasized that African countries who are fragile and conflict-affected can't afford the costs of climate adaptation on their own and they urgently need long-term support from international development partners [55]. For institutional Weakness there is limited capacity and expertise in climate risk mitigation and policy implementation and there are inadequate institutional frameworks for climate change mitigation and adaptation for African countries. This is consistent with prior research that highlights institutional challenges to adaptation to climate change in Africa (e.g. [56]). The inadequate legal framework supporting most African countries' climate risk mitigation could be due to the lack of comprehensive climate change laws and regulations in most African countries and there are insufficient legal frameworks to support their climate risk mitigation and adaptation efforts. This is consistent with prior research that stressed this observation (e.g., [57]). The Lack of intersectoral coordination in climate risk mitigation in Africa could be attributed to limited collaboration and coordination between countries, government ministries, departments, and agencies in most African countries and the insufficient engagement with non-state actors, such as civil society organizations and the private sector in most African countries. This confirms [58], observation of African country's efforts in climate risk mitigation. The political challenges that African countries face could also be attributed to competing priorities and less political will to address climate change and the Potential conflicts between economic development and climate risk mitigation and adaptation efforts [59].

Also, the lack of impact from African countries' financial development, competitive environment, and national governance systems on the relationship between climate risk and financial stability emphasized a crucial point that: African economies are heavily dependent on climate-sensitive industries and products, with limited capacity to adapt to changing conditions. They rely on climate-sensitive industries such as agriculture, mining, fisheries, forestry and others that are highly vulnerable to climate change. Furthermore, the limited capacity to adapt is caused by insufficient resources, infrastructure challenges, and less technological advancement hindering their adaptation efforts. This is consistent with, Baarsch et al. [6] and Mensah et al., [60], observation that the economic development of some African countries is fragile and with poorly coordinated approaches to adapt to the future climate change risk. This also supports Steiner [61], assertion that African economies rely heavily on climate-sensitive industries for development, and they are inadequately prepared to respond to climate changes. This confirms the United Nations Economic Commission for Africa [28] observation that African countries have fragile economies, weak institutions, and inadequately developed governance structures. For example, Agriculture as the main source of foreign exchange for African countries accounting for about 40 % of the continent's hard currency earnings and as the main generator of savings and tax revenues, is sensitive to changing climate, due to reliance on rainfall, poor technological usage, poor maintenance of irrigational systems, insecure land tenure and other factors.

Other factors that may also contribute to the findings of this study are briefly elaborated on as follows: (1) The short period of the study focuses on five years before and after the Paris Agreement. Climate risk impacts are often on a long-term basis and the immediate financial stability impact might not be obvious. However, the compounding nature of climate risk exposure would cause financial instability in African countries. (2) Although the enactment of the Paris Agreement aims to help African countries in their management of climate risk exposure and to impact positively on their financial stability. The nonsignificant impact could be attributed to less commitment from African governments, regulators and financial regulators in resolving challenges posed by climate change in Africa. This means African countries are less committed to energy conservation, carbon emissions reduction, environmental pollution reduction and other climate risk management systems. (3) The globalization system of trading might also have accounted for the nonsignificant impact of climate risk exposure on the financial stability of African countries before and after the Paris Agreement. The disadvantages or benefits associated with other continents' financial systems resulting from climate risk exposure would have a tripling effect on the African continent's financial stability resulting in the nonsignificant impact of climate risk on their financial stability following the Paris Agreement enactment. This highlights the need for a global effort in resolving climate change challenges for it to have an impact on African country's financial stability following the Paris Agreement enactment. (4) African countries are still adopting less technological innovations in addressing many climate risk exposure issues in the face of global climate risk exposure or change impacting negatively. This highlights the need for improvement in technological innovations in mitigating climate change challenges in Africa the Paris Agreement enactment. (5) Although, the insurance industry in Africa is growing the magnitude of climate risk exposure on financial stability in the African continent has been overwhelmed following the Paris Agreement and this highlights the need for more investment in the insurance industry in Africa to help mitigate climate risk exposure following the Paris Agreement. For example, Cyclone Idai, in Mozambique in 2019, was the most expensive climate disaster recorded in Africa in 2019 resulting in an economic loss of almost two billion U.S. dollars [62]. African countries can also address the limited insurance penetration issue by Increasing awareness and education on insurance relating to climate risk, the insurance industry in Africa should also develop tailored insurance products to meet the peculiar climate risk mitigation challenges in Africa. In addition, the insurance industry should enhance and promote the affordability and accessibility of insurance products and services relating to climate risk mitigation. Finally, African countries' governments should Implement policies and regulations that support the development of the insurance industry. (6) The non-significant impact of climate risk on the financial stability of African countries following the enactment of the Paris Agreement could also be attributed to the growth being experienced in African financial markets and economy with associated less efforts in resolving climate risk issues, reducing greenhouse gas emissions and less support for policies in resolving climate change issues. This calls for the need for much effort in improving funding in Climate resilient sustainable programs to cope with the growth in the African economy.

Finally, the non-significant impact of financial development, competitive environment and national governance system on the relationship between climate risk and financial stability in African countries could be attributed to the fact that African countries face challenges in achieving the United Nations (UN) 17 Sustainable Development Goals (SDGs), which includes climate action and mitigating climate change challenges. These challenges they face include but are not limited to limited financial resources and capacity, pressing development challenges, such as infrastructure, poverty, health and education and Some African countries are also having governance challenges, conflicts and political instability accounting for the nonsignificant impact of climate risk on financial stability following the Paris Agreement enactment.

The findings have several implications for African countries' financial stability, which might suggest that the financial system monitoring of most African countries might have failed to integrate many key elements of climate-related risk in their financial management considering the serious problems created in Africa due to climate risk exposure. Thus, African countries need to leverage regional partnerships (e.g., the African Financial Alliance on Climate Change), which will help coordinate climate risk mitigation actions, help them build capacity on climate issues, enhance climate finance mobilization, and encourage and facilitate climate risk mitigation knowledge sharing among Africa countries. Furthermore, African countries are encouraged to seek climate funds, scientific information and technical guidance from the International Climate Finance bodies, which will support their climate adaptation and mitigation efforts, help mobilize funding for their climate projects, improve their resilience to climate change impacts, and help them achieve sustainable development and transition to low-carbon economies. In addition, the discovery of the non-significant impact highlights the need for more research and analysis concerning climate risk integration into African countries' financial stability monitoring which will go a long way to improve upon the understanding of climate risk exposure in Africa and its impact on their financial system. Also, this highlights the fact that there is less transparent on matters relating to climate-related financial exposure in African countries and there is a need for more transparent efforts to help in the understanding of the nature and scope of climate risk exposure on the financial stability of African countries who are facing adverse impact of climate risk exposure, these support the observations of Brunetti et al., [63] on matters of climate risk and financial stability.

Aside from the above implications other implications for African countries and regulators are as follows. Firstly, there is a need for African countries and regulators to commit themselves or implement policies that consider climate mitigation in their developmental projects for the Paris Agreement to make an impact on their climate risk exposure and their financial stability. Secondly, technology and digitalization are helping in mitigating climate change challenges and African countries need to adopt innovative technology in their effort to mitigate climate change challenges for them to benefit from the enactment of the Paris Agreement. Thirdly, these findings highlight that climate change challenges are not an issue that can be resolved by one country, one continent, or a group of countries, but by concerted efforts globally and international corporations are needed to mitigate climate risk exposure. Therefore developed, developing and least developed countries must pool resources to mitigate climate change challenges. Fourthly African countries must integrate climate risk management system in their governance for it to have a positive impact on the climate risk and their financial stability relationship, in addition seriously address the governance challenges they face in achieving UN sustainable developmental goals. Fifthly, The African Financial Alliance on Climate Change's goal of bringing together leaders in the African financial industry to increase financial sector participation in climate action and supporting low-carbon and climate-resilient development in Africa should be supported and sustained globally. Sixthly, the challenges associated with climate change are increasing globally for the Paris Agreement to make an impact in African countries there is the need for a scale-up in private climate finance in Africa which must be supported by multilateral development banks, the IMF, and the public sector which is in line with the recommendations of the Global Financial report [37] and there must be financial, technical, and capacity-building support for African countries in the mitigation of climate risk challenges.

The policy recommendations are as follows: Given the empirical results, African countries should implement policies that reduce reliance on climate-sensitive sectors such as agriculture, mining, fisheries, and forestry. Thus, diversifying into services, manufacturing and other digital economies to help in their climate risk mitigation and strengthen their financial stability. Also, African countries should align their policies both at the national and local levels on climate risk mitigation with the Paris Agreement to improve their climate mitigation efforts and help attract climate finance, which would enhance their financial stability. In addition, there is the need for increased government spending and investment in climate risk mitigation measures such as early warning systems, infrastructure, promotion of sustainable agriculture and collaboration between governments, governments and the private sector to help in their climate risk mitigation and reduce their vulnerability, which will improve their financial stability. Moreover, there should be reforms focusing on deepening financial markets, improving climate risk mitigation regulatory frameworks, and enhancing access to credit on climate-resilient projects in building or strengthening the financial stability of African countries. Finally, African countries should promote good governance practices concerning transparent governance and others such as anti-corruption measures as these are critical to effectively implementing climate risk mitigation measures and financial policies, which help in promoting financial stability.

5. Conclusion and limitations

As there is no empirical evidence comparing the impact of climate risk on financial stability in Africa following the enactment of the Paris Agreement the study focuses on 32 African countries due to the availability of data on them, and five years before and after the enactment of the Paris Agreement, therefore future research should incorporate more African countries and consider a longer time frame to help broaden the understanding of the climate risk and financial stability relationship from African perspective. Future research could also explore how external climate funding, cultural factors and other variables relating to African countries may influence the climate risk and financial stability relationship following the enactment of the Paris Agreement. Also, the study uses climate risk data sourced from the Germanwatch organization which only focuses on weather-related events therefore, future research could adopt other climate risk measurements (e.g., University of Notre Dame – the Notre Dame Global Adaptation Initiative, ND-GAIN index) to help in broadening the understanding of climate risk and financial stability relationship. Fourthly, the study only uses the World Bank Z score as a measure of financial stability other measures like nonperforming loans could also be considered and other theoretical perspectives like the network, system risk, Portfolio and others could be adopted to explain the climate risk, the Paris Agreement and the financial stability relationship. Also, other variables like leadership style moderating the relationship between climate risk and financial stability in Africa could be considered. Finally, a comparative study with other continents would also help broaden the understanding of climate risk and financial stability relationships following the enactment of the Paris Agreement.

CRediT authorship contribution statement

Joseph Opuni-Frimpong: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The author has no competing interest.

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Data availability

Data will be made available on request.

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