Climate change risk and financial sector development in the EMEA region: Evidence from the pooled mean group autoregressive distributed lag (PMG-ARDL) approach

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Climate change risk; Financial sector development; Financial markets; Financial institutions; PMG-ARDL; EMEA; Sustainable finance

Abstract
This study examines the impact of climate change risk on financial sector development in selected Europe, Middle East and Africa (EMEA) countries. Specifically, it investigates the long-run and short-run effects of climate change risk on financial market and financial institution development while assessing regional heterogeneity across the EMEA region. The study employs annual panel data for selected EMEA countries obtained from the International Monetary Fund, World Bank, Notre Dame Global Adaptation Initiative (ND-GAIN), and other internationally recognised databases. Financial sector development is measured using the International Monetary Fund's Financial Development Index, while climate change risk is captured using a composite Climate Change Risk Index. The Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) estimator is utilised to estimate both long-run and short-run relationships following panel unit root, cross-sectional dependence, multicollinearity, and cointegration diagnostics. The empirical findings indicate that climate change risk exerts heterogeneous effects on financial sector development across the EMEA region. In the long run, climate change risk positively influences financial market development in countries with advanced financial systems and strong climate finance mechanisms, particularly in Europe. Conversely, climate change risk adversely affects financial institution development in several African and Middle Eastern economies characterised by lower institutional resilience and regulatory capacity. The findings highlight the need for climate-responsive financial regulation, strengthened institutional resilience, expanded sustainable finance initiatives, and region-specific policy interventions to enhance financial sector sustainability under increasing climate uncertainty.

Introduction

Climate change has become one of the most significant threats to global economic and financial systems, extending beyond environmental degradation to influence macroeconomic stability, financial markets, and institutional resilience. Increasing temperatures, changing precipitation patterns, biodiversity loss, and the rising frequency of extreme weather events have intensified both physical and transition risks, creating substantial challenges for financial systems worldwide. Financial institutions, investors, regulators and governments are increasingly recognising climate change as a systemic source of financial risk that affects investment decisions, asset valuations, credit allocation and long-term economic development (Battiston et al., 2021; IMF, 2019; European Commission, 2024a). Recent evidence further indicates that climate-related economic losses continue to rise globally, reinforcing the urgency of integrating climate risk into financial sector policy and regulation.

Financial sector development plays a critical role in promoting sustainable economic growth through the mobilisation of savings, efficient allocation of capital, risk diversification and the provision of financial services. The World Bank's 4×2 Financial Development Framework conceptualises financial sector development along two broad dimensions inancial markets and financial institutions each measured through four key components: access, depth, efficiency and stability. This multidimensional framework provides a more comprehensive assessment of financial system performance than conventional single-indicator measures. However, climate change increasingly threatens these dimensions by disrupting economic activity, increasing financial uncertainty, altering investment behaviour and exposing financial institutions to greater credit, market and operational risks. Consequently, climate change risk has become an important determinant of financial sector development rather than merely an environmental concern.

Climate change affects financial systems primarily through physical and transition risk channels (Takawira, et al 2026). Physical risks arise from climate-related disasters such as floods, droughts, storms, wildfires and heatwaves, which damage productive assets, reduce economic output and impair borrowers' repayment capacity. Transition risks emerge from policy reforms, technological innovation, carbon pricing mechanisms and changing investor preferences as economies move towards low-carbon development. These risks influence financial systems through declining asset values, increased default probabilities, higher insurance claims, changing portfolio allocations and increased financial market volatility (Fu et al., 2023; Grippa et al., 2019; Battiston et al., 2021). As climate-related risks intensify, regulators and central banks have increasingly advocated the incorporation of climate stress testing, scenario analysis and climate risk disclosure into prudential supervision to strengthen financial system resilience.

The importance of understanding these relationships is particularly evident within the Europe, Middle East and Africa (EMEA) region. EMEA comprises economies that differ substantially in terms of financial market maturity, institutional quality, regulatory capacity, climate vulnerability and economic development. European countries generally possess relatively sophisticated financial systems, stronger climate finance mechanisms and more advanced regulatory frameworks, whereas many African and Middle Eastern economies remain highly vulnerable to climate shocks while simultaneously facing weaker institutional capacity and limited climate adaptation finance. These structural differences imply that climate change risk is unlikely to affect financial sector development uniformly across the three regions, thereby necessitating comparative empirical investigation.

Review of Literature

The relationship between climate change risk and financial sector development has attracted increasing attention as climate-related physical and transition risks become more deeply embedded in financial markets and institutions. Climate change can affect the financial sector by damaging assets and infrastructure, reducing borrowers' repayment capacity, altering investment returns, increasing insurance claims and exposing financial institutions to credit, liquidity, market and operational risks . At the same time, financial systems can facilitate climate adaptation and mitigation by mobilising capital for renewable energy, climate-resilient infrastructure and low-carbon technologies. The literature therefore presents a two-way relationship in which climate change influences the development and resilience of financial systems, while financial institutions and markets shape economies' capacity to respond to environmental risks. However, the direction and magnitude of these effects differ according to institutional strength, financial depth, regulatory capacity and regional economic conditions.

Theoretical Literature

The theoretical relationship between climate change risk and financial sector development cannot be explained adequately by a single theory. The present study therefore draws on several complementary theories and analytical frameworks, including Systemic Risk Theory, the Efficient Market Hypothesis, the Financial Instability Hypothesis, the Systems Theory of Financial Inclusion, the Dynamic Integrated Climate–Economy model, the Ecological Stock-Flow Consistent model and the Dystopian Schumpeter Meeting Keynes model. Collectively, these perspectives explain how climate-related shocks are transmitted through asset prices, lending activities, financial networks, market expectations, institutional behaviour and the broader macroeconomy. Nevertheless, the reviewed literature confirms that no comprehensive theory currently integrates all dimensions of climate change risk and financial sector development namely access, depth, efficiency and stability across both financial institutions and financial markets.

Systemic Risk Theory provides an important foundation for explaining how climate-related shocks can spread throughout an interconnected financial system (Marimo and Takawira, 2026). The theory suggests that distress affecting one institution, market or economic sector may be transmitted to other components of the financial system through direct financial exposures, correlated assets, liquidity pressures and changes in investor behaviour. Climate-related disasters can reduce property and collateral values, weaken firms' cash flows and increase credit defaults. These effects may initially appear localised but can spread through banks, insurance companies, securities markets and investment portfolios. Similarly, transition policies may cause the repricing of carbon-intensive assets and create stranded-asset risks for institutions with substantial exposure to fossil-fuel-dependent sectors. Climate change may therefore become a systemic risk when losses are transmitted across highly interconnected financial institutions and markets.

The Efficient Market Hypothesis provides a financial-market perspective by proposing that asset prices incorporate available information. Under this framework, information about climate vulnerability, carbon regulation, environmental liabilities and transition strategies should be reflected in securities prices. Investors may reduce the value of companies exposed to severe physical climate risks or carbon-intensive activities while assigning higher valuations to firms that demonstrate stronger climate resilience and sustainable business practices. However, the theory assumes that relevant information is available, accurately measured and efficiently processed by market participants. In practice, incomplete climate disclosures, uncertainty regarding future regulation and the long-term nature of environmental risks may prevent climate information from being fully incorporated into market prices. Consequently, apparent financial-market stability may conceal climate vulnerabilities that have not yet been adequately priced.

The Financial Instability Hypothesis further explains how periods of financial expansion can generate increasing vulnerability as institutions become more willing to accept risk. During prolonged periods of economic and financial stability, lenders and investors may underestimate climate-related threats and continue financing carbon-intensive or climate-sensitive activities. This can create concentrated exposures and asset-price distortions that become apparent only when a climate shock or policy transition occurs. The hypothesis is particularly relevant where short-term profitability considerations discourage institutions from accounting for long-term environmental risks. Climate change may therefore amplify existing financial fragilities by exposing weaknesses accumulated during periods of optimistic lending, investment and risk assessment.

The Systems Theory of Financial Inclusion extends the analysis to financial access by viewing financial inclusion as the outcome of interactions among institutions, markets, regulations, technology and social conditions. Climate shocks can interrupt access to banking facilities, reduce household income, damage business operations and weaken the ability of vulnerable groups to qualify for formal financial services. Conversely, accessible savings, insurance, credit and digital payment systems may improve the capacity of households and businesses to absorb climate shocks and finance recovery. This perspective suggests that the effects of climate change on financial development are not confined to financial stability, but extend to the ability of individuals and enterprises to obtain and use financial services.

Integrated assessment models also contribute to the theoretical foundation of the study. The Dynamic Integrated Climate–Economy model connects economic activity, greenhouse-gas emissions, climate damage and mitigation costs, thereby illustrating how climate change can alter output, investment and welfare over time. The Ecological Stock-Flow Consistent model incorporates environmental constraints into the interdependent financial and real sectors of the economy, allowing climate-related changes in production, credit, income and wealth to be examined simultaneously. The Dystopian Schumpeter Meeting Keynes framework further introduces technological innovation, financial dynamics and climate damage into an agent-based setting. These models collectively demonstrate that the relationship between climate risk and financial development is dynamic, nonlinear and dependent on feedback mechanisms among environmental, economic and financial systems. Accordingly, climate change may simultaneously constrain conventional financial activity and stimulate new financial opportunities through green innovation, sustainable investment and climate finance.

Empirical Literature

The empirical literature generally recognises that climate change affects financial systems through physical and transition-risk channels, although the findings remain mixed across measures, countries and methodologies. Physical climate risks can reduce asset values, disrupt production, weaken borrower repayment capacity and increase insurance losses, while transition risks can alter the profitability of carbon-intensive firms and expose financial institutions to policy, technological and reputational shocks. Grippa et al. (2019) argue that climate risks manifest through increased loan-default probabilities and the revaluation of financial assets. Battiston et al. (2021) similarly identify climate change as a source of systemic financial risk and emphasise the need for financial institutions to evaluate their exposure to climate-sensitive sectors. Wu et al. (2023) show that climate risks can reduce financial returns, increase market volatility and transmit instability through banking, insurance and securities markets.

Evidence relating to financial-market development is not uniform. Some studies suggest that climate risk weakens market stability by increasing uncertainty, volatility and the probability of abrupt asset-price corrections. Climate-related disasters may reduce corporate earnings, disrupt supply chains and increase risk premiums, thereby lowering stock-market returns and discouraging investment (Amo-Bediako, Takawira and Choga, 2025). Transition policies may similarly reduce the valuation of firms whose business models depend heavily on fossil fuels. In contrast, other studies indicate that growing climate risk can stimulate financial-market depth by increasing the issuance of green bonds, sustainability-linked instruments and climate-related investment products. Developed financial markets may respond to climate risk by creating new opportunities for capital mobilisation, risk diversification and technological innovation. This helps explain why climate change may have a positive association with financial-market development in economies possessing sophisticated markets and established climate-finance frameworks.

Empirical evidence concerning financial institutions also reveals contrasting effects. Climate shocks can weaken banking stability through higher non-performing loans, declining collateral values and reduced borrower income. Insurance institutions face increased claims following floods, storms, droughts and other extreme events, while banks may encounter liquidity and capital pressures when climate-related losses become widespread. Beck and Poelhekke (2023) emphasise the need for financial institutions to incorporate environmental risks into lending and investment decisions. Fu et al. (2023) further note that physical and transition risks can affect the valuation of financial assets and institutional portfolios. These adverse effects are expected to be more pronounced in countries where supervision, financial infrastructure and adaptation capacity remain weak.

Despite these risks, developed financial institutions can also support climate resilience. Banks may finance renewable energy, climate-smart agriculture, clean technologies and resilient infrastructure, while insurers can provide products that transfer climate-related losses (Gangata and Takawira, 2025). Green credit and sustainable investment can therefore deepen financial intermediation and create new financing channels. Apeaning and Labaran (2025) argue that developed financial systems are important for mobilising resources for climate-mitigation innovation. Paramati et al. (2021) and Tolliver et al. (2020) similarly associate financial development with support for green technology and sustainable investment. The impact of climate change on institutional development may therefore depend on whether financial institutions possess the regulatory capacity, financial resources and expertise required to transform climate pressures into sustainable financing opportunities.

The regional evidence reinforces the importance of economic and institutional heterogeneity. European economies generally have deeper capital markets, stronger financial regulation and more developed climate-finance instruments. Consequently, climate risk may encourage the expansion of green bonds, sustainable funds and environmental disclosure systems, thereby supporting certain dimensions of market development. By comparison, many African economies experience high exposure to physical climate risks alongside shallow financial markets, limited insurance coverage and constrained adaptation finance. The Middle East faces a distinctive combination of physical risks and transition exposure arising from the importance of hydrocarbons to national income and financial-sector activity. A transition away from fossil fuels may create stranded assets and weaken the value of carbon-dependent investments, although it may also accelerate diversification and sustainable-finance development.

Overall, the empirical literature suggests that the effects of climate change on financial sector development are multidimensional and region-specific. Climate risk may reduce financial access, stability and efficiency in vulnerable economies, while stimulating financial depth and sustainable investment in countries with more advanced financial systems. The extended abstract reports that climate change risk is positively associated with financial-market development in the long run, particularly in Europe, but negatively affects financial-institution development in regions with weaker regulatory depth and institutional resilience. It also indicates adverse effects on financial access and depth in Africa, contrasting with positive effects on depth and mixed access outcomes in Europe and the Middle East. These differences support the use of models that explicitly recognise regional heterogeneity and distinguish between financial markets and financial institutions.

Methodology

Data and Variables

This study adopts a quantitative research design to examine the impact of climate change risk on financial sector development in selected Europe, Middle East and Africa (EMEA) countries. Annual panel data covering the study period were compiled from internationally recognised databases to ensure consistency, comparability and reliability. Financial sector development indicators were obtained from the International Monetary Fund (IMF) Financial Development Database, while climate change risk indicators were sourced from the Notre Dame Global Adaptation Initiative (ND-GAIN) database. Macroeconomic control variables, including real gross domestic product (RGDP) and inflation (INF), were collected from the World Development Indicators (WDI) published by the World Bank. These databases are widely used in cross-country financial and climate-related studies because they provide harmonised and internationally comparable indicators.

Financial sector development was measured using the World Bank's 4×2 Financial Development Framework, which captures two major components of the financial system, namely financial markets and financial institutions. Each component comprises four dimensions: access, depth, efficiency and stability. Following the IMF Financial Development Database, two composite indices were employed in this study: the Financial Markets Sub-Index (FMSI) and the Financial Institutions Sub-Index (FISI). The FMSI reflects the development of equity and bond markets through indicators measuring market access, depth and efficiency, whereas the FISI measures banking sector and financial institution performance through indicators of institutional access, depth, efficiency and stability (Sahay et al., 2015).

Climate change risk was proxied by the Climate Change Risk Index (CCRI) obtained from the ND-GAIN database. The index measures a country's vulnerability to climate-related shocks while incorporating its adaptive capacity and readiness to respond to climate change. Higher CCRI values indicate greater exposure to climate-related risks that may adversely affect economic performance and financial systems. To minimise omitted-variable bias, the study controls for real gross domestic product (RGDP) and inflation (INF), both of which have been widely recognised as important determinants of financial sector development. Table 1 presents the variables employed in the empirical analysis.

Table 1. Description of Variables

Variable	Measurement	Expected Sign	Source
Financial Markets Sub-Index (FMSI)	IMF Financial Development Index	Dependent	IMF Financial Development Database
Financial Institutions Sub-Index (FISI)	IMF Financial Development Index	Dependent	IMF Financial Development Database
Climate Change Risk Index (CCRI)	ND-GAIN Climate Risk Index	±	ND-GAIN Database
Real Gross Domestic Product (RGDP)	Constant US$ (logged)	+	World Development Indicators
Inflation (INF)	Consumer Price Index (Annual %)	−	World Development Indicators

Model Specification

The empirical analysis is based on the financial development framework, which postulates that financial sector development is influenced by climate-related risks and macroeconomic conditions. Accordingly, the functional relationship is expressed as

$$\mathrm{FSD} = \mathrm{f}(\mathrm{CCRI}, \mathrm{RGDP}, \mathrm{INF})$$

where:

- FSD denotes financial sector development measured separately by the Financial Markets Sub-Index (FMSI) and Financial Institutions Sub-Index (FISI);
- CCRI represents climate change risk;
- RGDP denotes real gross domestic product; and
- INF represents inflation.

Two empirical models are estimated.

Model 1: Financial Markets

$$FMSI_{it} = \beta_0 + \beta_1 CCRI_{it} + \beta_2 RGDP_{it} + \beta_3 INF_{it} + \varepsilon_{it}$$

Model 2: Financial Institutions

$$FISI_{it} = \beta_0 + \beta_1 CCRI_{it} + \beta_2 RGDP_{it} + \beta_3 INF_{it} + \varepsilon_{it}$$

where

- $i = 1, \dots, N$denotes countries;
- $t = 1, \dots, T$denotes time;
- $\beta_0$is the intercept;
- $\beta_1 - \beta_3$are the slope coefficients; and
- $\varepsilon_{it}$is the error term.

To improve normality and minimise heteroscedasticity, the continuous variables were transformed into natural logarithms before estimation.

Estimation Technique: PMG-ARDL

The study employs the Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) estimator developed by Pesaran, Shin and Smith (1999). The PMG estimator is particularly appropriate for macro-panel datasets characterised by heterogeneous countries because it allows the long-run coefficients to remain homogeneous across countries while permitting short-run dynamics, intercepts and error variances to differ. This feature is particularly relevant for the EMEA region, where countries exhibit substantial differences in financial development, institutional quality, economic structures and climate vulnerability.

Compared with conventional panel estimators such as Fixed Effects, Random Effects and Generalised Method of Moments (GMM), the PMG estimator offers several advantages. First, it simultaneously estimates long-run equilibrium relationships and short-run adjustment processes. Second, it accommodates regressors integrated of order I(0) and I(1) without requiring all variables to have the same order of integration, provided none is integrated beyond I(1). Third, it produces efficient and consistent estimates under heterogeneous panel settings where countries adjust differently towards long-run equilibrium.

The PMG-ARDL error correction specification is expressed as

$$\Delta Y_{it} = \phi_i (Y_{it-1} - \theta_i X_{it-1}) + \sum_{j=1}^{p-1} \lambda_{ij} \Delta Y_{it-j} + \sum_{j=0}^{q-1} \delta_{ij} \Delta X_{it-j} + \mu_i + \varepsilon_{it}$$

where

- Y_{it}denotes financial sector development;
- X_{it}represents the vector of explanatory variables;
- $\phi_i$is the error correction coefficient;
- $\theta_i$represents the long-run coefficients;
- $\lambda_{ij}$and δ_{ij}denote the short-run dynamics;
- $\mu_i$captures country-specific effects; and
- $\varepsilon_{it}$is the disturbance term.

A negative and statistically significant error correction coefficient confirms the existence of a stable long-run relationship among the variables.

Empirical Results

This section presents and discusses the empirical findings on the impact of climate change risk on financial market stability and financial institution stability in selected EMEA countries. The analysis begins with descriptive statistics and correlation analysis, followed by cross-sectional dependence, panel unit root and cointegration tests. The section then reports the short-run and long-run PMG-ARDL estimates for the two study models and concludes with an assessment of regional heterogeneity across Africa, Europe and the Middle East. The analysis is based on 1,870 country-year observations covering 55 EMEA countries over the period 1990–2023.

Descriptive Statistics

Table 1 presents the descriptive statistics for the variables included in Models 1 and 2.

Table 1. Descriptive Statistics

Variable	Observations	Mean	Median	Std. Dev.	Minimum	Maximum	Skewness	Kurtosis
FMSI	1,87	0.000	−0.172	1.038	−1.241	31.320	15.418	444.074
FISI	1,87	0.000	0.028	1.025	−5.475	4.047	−0.281	1.308
CCRI	1,87	0.000	−0.111	1.132	−1.630	7.698	2.994	14.083
RGDPz	1,87	0.355	0.356	0.041	0.000	1.000	2.043	45.105
INFz	1,87	0.054	0.048	0.039	0.000	1.000	14.611	273.741

Source: Authors' computations from the EMEA dataset.

The standardised indices have mean values close to zero, reflecting the transformations applied before estimation. The Financial Market Stability Index (FMSI) displays considerable variability, ranging from −1.241 to 31.320. Its high positive skewness and kurtosis indicate a strongly right-skewed and heavy-tailed distribution, suggesting that most countries recorded relatively moderate market stability, while a few observations exhibited exceptionally high values. By comparison, the Financial Institution Stability Index (FISI) is more evenly distributed, with mild negative skewness and substantially lower kurtosis.

The Climate Change Risk Index (CCRI) is positively skewed and leptokurtic, demonstrating substantial differences in climate vulnerability across the EMEA countries. Most observations are concentrated below the mean, while a smaller number of countries experience considerably higher climate risk. The standardised inflation variable also exhibits pronounced skewness and kurtosis, reflecting extreme inflationary episodes in a limited number of economies. These distributional characteristics confirm substantial macroeconomic, financial and climatic heterogeneity across the sample and support the use of an estimator that permits heterogeneous short-run responses and does not rely heavily on the assumption of normally distributed regressors.

Correlation Analysis

Table 2 reports the Pearson correlation coefficients among the variables included in the two models.

Table 2. Pearson Correlation Matrix

Variable	FMSI	FISI	CCRI	RGDPz	INFz
FMSI	1.000				
FISI	0.027	1.000			
CCRI	0.117	−0.122	1.000		
RGDPz	−0.068	0.036	−0.133	1.000	
INFz	0.077	0.071	0.072	−0.185	1.000

Source: Authors' computations from the EMEA dataset.

Climate change risk has a weak positive correlation with financial market stability ($r = 0.117$) and a weak negative correlation with financial institution stability ($r = -0.122$). These coefficients suggest that the direct contemporaneous linear association between climate risk and the two financial stability measures is limited. However, weak correlation does not exclude dynamic or long-run relationships, which are subsequently examined through the PMG-ARDL estimator.

RGDPz is weakly negatively correlated with FMSI but weakly positively correlated with FISI. Inflation has weak positive relationships with both financial market and institution stability. The highest absolute correlation among the explanatory variables is only 0.185, between RGDPz and INFz. Since all coefficients are substantially below the conventional threshold of 0.80, severe multicollinearity is unlikely. This conclusion is consistent with the reported VIF values of approximately 1.02–1.05 and a mean VIF of 1.03. The thesis similarly reports that CCRI is only weakly associated with most financial-sector indicators, indicating that its effects may be indirect, delayed or nonlinear rather than immediately visible through simple correlations.

Cross-Sectional Dependence

The Pesaran CD test was conducted to establish whether shocks affecting one EMEA economy are correlated with developments in other countries. The results for the variables relevant to Models 1 and 2 are presented in Table 3.

Table 3. Pesaran Cross-Sectional Dependence Test

Variable	CD statistic	p-value	Mean correlation	Mean absolute correlation	Decision
RGDP	62.74	0.000	0.28	0.32	Cross-sectional dependence
INF	60.15	0.000	0.27	0.32	Cross-sectional dependence
CCRI	22.83	0.000	0.10	0.35	Cross-sectional dependence
FMSI	53.52	0.000	0.23	0.31	Cross-sectional dependence
FISI	26.16	0.000	0.12	0.36	Cross-sectional dependence

Source: Authors' computations from Stata 18.

All p-values are below 0.05, leading to the rejection of the null hypothesis of cross-sectional independence. The results indicate that climate, macroeconomic and financial developments are interrelated across the sampled economies. This is reasonable because EMEA countries are connected through trade, capital flows, banking networks, energy markets and common global shocks. A climatic, economic or financial disturbance occurring in one country may therefore influence other countries within the region.

The presence of cross-sectional dependence means that conventional first-generation panel procedures based on independent cross-sectional units may produce biased inference. It consequently justifies the application of second-generation panel unit root tests and dynamic panel estimators capable of accommodating common shocks and heterogeneous responses.

Panel Unit Root Tests

Given the presence of cross-sectional dependence, the Cross-Sectionally Augmented Dickey–Fuller (CADF) second-generation panel unit root test was applied. Table 4 reports the results for the variables used in Models 1 and 2.

Table 4. CADF Panel Unit Root Test Results

Variable	Level: Constant	Level: Constant + trend	First difference: Constant	First difference: Constant + trend	Integration order

RGDP	−2.90**	−2.79**			I(0)
INF	−2.62**	−2.66**			I(0)
CCRI	−1.73	−2.18**	−3.90**	−3.98**	I(0)/I(1)
FMSI	−1.78	−2.26	−3.68**	−3.73**	I(1)
FISI	−1.76	−2.32	−3.69**	−2.83**	I(1)

*Note: ** denotes significance at the 5% level.*

Source: Authors' computations from Stata 18.

RGDP and inflation are stationary at levels under both the constant and constant-plus-trend specifications and are therefore classified as I(0). FMSI and FISI are non-stationary at levels but become stationary after first differencing and are classified as I(1). CCRI is stationary at level under the constant-plus-trend specification and is clearly stationary after first differencing.

The test therefore reveals a mixture of I(0) and I(1) variables, with none integrated of order two, I(2). This mixed integration structure supports the use of the PMG-ARDL estimator, which can accommodate regressors that are stationary at levels and after first differencing, provided that no variable is I(2).

Cointegration Tests

The Kao panel cointegration test was used to determine whether climate change risk, economic growth, inflation and the financial stability indicators share stable long-run relationships.

Table 5. Kao Panel Cointegration Test

Test	Model 1: FMSI	Model 2: FISI
t-statistic	−7.40	−1.85
p-value	0.000**	0.032**
Decision	Cointegrated	Cointegrated

*Note: ** denotes significance at the 5% level.*

Source: Authors' computations from Stata 18.

The Kao test statistics are negative and statistically significant for both models. The null hypothesis of no cointegration is therefore rejected, confirming the existence of long-run equilibrium relationships between financial stability, climate change risk, RGDP and inflation. This finding indicates that although the variables may deviate from one another temporarily, they tend to move towards a common equilibrium over time. The confirmation of cointegration provides further justification for estimating the long-run coefficients and short-run error-correction dynamics using the PMG-ARDL framework.

PMG-ARDL Estimation Results

Model 1: Financial Market Stability

The first model estimates the effects of climate change risk, economic growth and inflation on financial market stability:

$$\mathrm{FMSI}_{\mathrm{it}} = \beta_0 + \beta_1 \mathrm{CCRI}_{\mathrm{it}} + \beta_2 \mathrm{RGDP}_{\mathrm{it}} + \beta_3 \mathrm{INF}_{\mathrm{it}} + \varepsilon_{\mathrm{it}}.$$

Table 6. PMG-ARDL Results for Financial Market Stability

Variable	Long-run coefficient	Standard error	Short-run coefficient	Standard error
CCRI	−0.289	0.169	0.602	0.544
RGDPz	−10.195**	1.323	3.503**	0.531
INFz	−1.297	1.022	17.643**	6.343
ECT	–	–	−0.297**	0.026
Constant	–	–	1.124**	0.109

*Note: ** denotes significance at the 5% level.*

Source: Authors' computations from Stata 18.

The long-run coefficient of CCRI is negative but statistically insignificant. Similarly, its short-run coefficient is positive but insignificant. These results indicate that climate change risk does not exert a statistically identifiable direct effect on financial market stability in either the short or long run across the full EMEA sample. The finding may indicate that market-based systems possess regulatory buffers, portfolio-diversification mechanisms and pricing processes that partly absorb immediate climate shocks. It may also reflect the gradual and indirect manner in which physical and transition risks enter asset values and financial-market indicators.

RGDP has contrasting short-run and long-run effects. Its short-run coefficient is positive and significant, indicating that an improvement in real economic growth initially strengthens financial-market stability. Increased output can support corporate earnings, investor confidence and trading activity. However, the long-run coefficient is negative and significant, suggesting that persistent growth may be associated with increased financial-market exposure, leverage or risk-taking. This result may also reflect the diverse structural characteristics of the sampled countries, where economic expansion does not always translate into more stable markets.

Inflation is statistically insignificant in the long run but positive and significant in the short run. The short-run positive coefficient may reflect the ability of nominal asset prices, earnings and market turnover to adjust during moderate inflationary episodes. Nevertheless, the insignificant long-run result suggests that inflation does not consistently explain financial-market stability after longer-term adjustment.

The error-correction coefficient is negative and statistically significant. Its value of −0.297 indicates that approximately 29.7% of a deviation from long-run equilibrium is corrected within one year. This confirms the stability of the estimated dynamic relationship and implies that financial-market stability returns gradually to its equilibrium path following climate or macroeconomic disturbances.

Model 2: Financial Institution Stability

The second model examines the effects of climate change risk and the macroeconomic controls on financial institution stability:

$$\mathrm{FISI}_{it} = \beta_0 + \beta_1 \mathrm{CCRI}_{it} + \beta_2 \mathrm{RGDP}_{it} + \beta_3 \mathrm{INF}_{it} + \varepsilon_{it}.$$

Table 7. PMG-ARDL Results for Financial Institution Stability

Variable	Long-run coefficient	Standard error	Short-run coefficient	Standard error
CCRI	1.270**	0.262	−0.135	0.187
RGDPz	−1.370	1.430	0.754**	0.331
INFz	−4.904**	1.704	12.902**	5.327
ECT			−0.157**	0.016
Constant			0.162**	0.043

*Note: ** denotes significance at the 5% level.*

Source: Authors' computations from Stata 18.

Climate change risk has an insignificant negative short-run coefficient but a positive and statistically significant long-run coefficient. A one-unit increase in CCRI is associated with an approximately 1.27-unit increase in financial institution stability over the long term. Although this result is contrary to the initial expectation of a negative relationship, it may indicate that persistent exposure to climate risk encourages financial institutions to strengthen capital buffers, adopt climate-risk management systems, adjust loan portfolios, improve disclosures and introduce climate-resilient lending and insurance products.

The insignificant short-run coefficient suggests that these institutional adjustments do not occur immediately. Climate-related risks may initially be absorbed through existing capital, liquidity and risk-management structures before generating meaningful changes in institutional stability.

RGDP has a positive and significant short-run coefficient but an insignificant long-run coefficient. Economic growth therefore appears to strengthen financial institutions in the short term through improved borrower income, higher deposits and stronger loan performance. Its long-run effect is less consistent across the heterogeneous EMEA economies.

Inflation has a positive short-run effect but a negative long-run effect. In the short run, inflation may increase nominal banking revenues and asset values. Over time, however, persistent inflation can weaken borrower repayment capacity, increase funding costs, reduce the real value of financial assets and create balance-sheet uncertainty. The long-run coefficient of −4.904 consequently indicates that sustained inflation constitutes a significant threat to institutional stability.

The error-correction coefficient is −0.157 and statistically significant, indicating that approximately 15.7% of disequilibrium is corrected annually. Financial institutions therefore return to long-run equilibrium more slowly than financial markets, which record an adjustment rate of 29.7%. This slower response is plausible because institutional balance sheets, loan portfolios and regulatory capital structures generally adjust gradually.

Regional Heterogeneity Analysis

The regional analysis distinguishes the effects of climate change risk across Africa, Europe and the Middle East. The results reveal substantial heterogeneity and demonstrate that pooled EMEA estimates can conceal important regional differences.

Table 8. Regional Effects of CCRI on Financial Market Stability

Region	Long-run coefficient	Standard error	Short-run coefficient	Standard error	ECT
Africa	−0.288	0.169	0.602	0.544	−0.297**
Europe	−0.195	0.186	−0.237	0.189	−0.317**
Middle East	−0.585	0.328	−0.579	0.461	−0.315**

*Note: ** denotes significance at the 5% level.*

Source: Authors' computations from Stata 18.

Climate change risk has negative but statistically insignificant effects on financial market stability in all three regions, in both the short and long run. The negative coefficients are largest in the Middle East, followed by Africa and Europe. Although statistically insignificant, this pattern may indicate that Middle Eastern financial markets are more exposed to climate-transition risks because of the region's dependence on hydrocarbon-related revenues and assets.

The statistically significant negative ECT coefficients confirm convergence towards equilibrium in all regions. Europe records the fastest adjustment, with approximately 31.7% of disequilibrium corrected annually, followed by the Middle East at 31.5% and Africa at 29.7%. Overall, the findings suggest a degree of financial-market resilience across the regions, although climate vulnerability may still be transmitted through dimensions other than stability, particularly efficiency, depth and access.

Table 9. Regional Effects of CCRI on Financial Institution Stability

Region	Long-run coefficient	Standard error	Short-run coefficient	Standard error	ECT
Africa	1.271**	0.262	−0.135	0.186	−0.157**
Europe	−0.180	0.093	−0.124	0.243	−0.157**
Middle East	−0.218**	0.104	0.780	0.577	−0.198**

*Note: ** denotes significance at the 5% level.*

Source: Authors' computations from Stata 18.

The regional results for financial institution stability differ substantially. In Africa, climate change risk has a significant positive long-run effect, implying that greater climate exposure is associated with strengthened institutional stability over time. This may reflect regulatory and institutional adaptation, including improved capital requirements, risk assessment and the growing integration of climate considerations into financial-sector policy. However, this result should not be interpreted as evidence that climate change itself is beneficial. Rather, it may capture the stabilising institutional responses triggered by increasing climate vulnerability.

In Europe, CCRI has a negative but statistically insignificant long-run effect. European financial institutions may be better positioned to absorb climate shocks because of stronger supervision, developed insurance markets, climate disclosure systems and established sustainable-finance frameworks. The insignificant coefficient may consequently reflect both underlying climate exposure and effective mitigation mechanisms.

In the Middle East, the long-run coefficient is negative and significant. A one-unit increase in CCRI reduces financial institution stability by approximately 0.218 units. This suggests that climate and transition risks may weaken financial institutions through hydrocarbon exposure, stranded-asset risk, water scarcity, extreme temperatures and economic concentration. The region nevertheless records the fastest institutional adjustment rate, with approximately 19.8% of disequilibrium corrected annually.

The broader regional results also show that climate risk reduces financial institution efficiency across all three regions. It significantly reduces institutional depth and access in Africa, while increasing depth in Europe and the Middle East. Access improves in Europe but deteriorates in Africa and the Middle East. Financial markets show a comparatively more favourable response: climate risk improves market efficiency in Africa and Europe, increases market depth in Europe and the Middle East, and enhances market access across all three regions. These patterns suggest that developed markets and robust climate-finance mechanisms enable some economies to transform climate risk into new financial products and investment channels, whereas institutionally weaker systems experience reduced lending capacity, higher costs and restricted financial access.

Overall, the results establish that the relationship between climate change risk and financial sector development is dynamic, multidimensional and region-specific. Climate risk does not significantly affect financial market stability in the pooled EMEA model, but it has a significant long-run effect on financial institution stability. The regional findings further demonstrate that the direction and magnitude of the relationship depend on institutional resilience, regulatory capacity, economic structure, digitalisation and the sophistication of climate-finance instruments. These results reinforce the importance of regionally differentiated climate-finance policies rather than uniform interventions across the EMEA region.

Policy Implications

The findings of this study have important implications for policymakers, financial regulators, central banks and financial institutions throughout the EMEA region.

First, governments should integrate climate risk considerations into national financial sector development strategies. Climate change should no longer be treated solely as an environmental issue but as a macro-financial risk capable of influencing financial stability, investment decisions and long-term economic development. National climate adaptation policies should therefore be closely aligned with financial sector policies to strengthen economic resilience.

Second, central banks and financial supervisory authorities should continue incorporating climate-related risks into prudential regulation and macroprudential supervision. Climate stress testing, environmental risk disclosure, scenario analysis and climate-related capital adequacy requirements should become integral components of financial sector oversight. These measures would improve the ability of financial institutions to identify, measure and manage climate-related risks before they evolve into systemic financial crises.

Third, policymakers should promote sustainable finance and expand green financial markets. The development of green bonds, sustainability-linked loans, climate funds and environmental investment products would facilitate the mobilisation of private capital towards climate adaptation and mitigation projects. Such initiatives would simultaneously strengthen financial market development while supporting the transition towards low-carbon economies.

Fourth, African economies require targeted interventions aimed at strengthening financial institutions and improving climate resilience. Governments should invest in financial infrastructure, improve regulatory quality, enhance institutional capacity and expand access to climate finance. International development partners should increase financial and technical support to vulnerable economies to improve their adaptive capacity and reduce climate-related financial risks.

Fifth, Middle Eastern countries should accelerate economic diversification strategies that reduce dependence on carbon-intensive industries. Transition risks associated with global decarbonisation policies pose significant challenges for financial institutions heavily exposed to fossil fuel sectors. Expanding renewable energy investments, sustainable infrastructure financing and diversified financial products would reduce long-term financial vulnerabilities.

Finally, international cooperation remains essential. Climate change represents a global challenge that transcends national boundaries. Regional financial institutions, multilateral development banks and international organisations should strengthen cooperation in developing common climate risk standards, improving climate data availability and supporting sustainable finance initiatives across the EMEA region.

Conclusion

This study examined the impact of climate change risk on financial sector development in selected EMEA countries using the Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) estimator. Financial sector development was examined separately through financial market stability and financial institution stability, while climate change risk was measured using the Climate Change Risk Index alongside real gross domestic product and inflation as control variables.

The empirical findings reveal that climate change risk has heterogeneous effects on financial sector development across the EMEA region. Climate change does not exert a statistically significant direct effect on financial market stability in the pooled sample, suggesting that financial markets possess considerable resilience in responding to climate-related information and shocks. In contrast, climate change risk positively influences financial institution stability in the long run, indicating that financial institutions may strengthen their resilience through improved climate risk management, regulatory reforms and sustainable finance initiatives. The results further demonstrate that economic growth enhances financial sector performance in the short run, whereas persistent inflation weakens financial institutions over longer horizons.

The regional analysis confirms that the effects of climate change differ substantially across Africa, Europe and the Middle East. European economies generally exhibit stronger financial resilience due to advanced financial markets, higher institutional quality and well-developed climate finance mechanisms. African countries remain relatively vulnerable because of weaker financial systems and limited climate adaptation capacity, while Middle Eastern economies face additional transition risks associated with dependence on carbon-intensive industries. These findings highlight the importance of recognising regional heterogeneity when designing climate-related financial policies.

The study makes several important contributions to the literature. First, it extends existing research by examining financial markets and financial institutions separately using the multidimensional IMF Financial Development Framework. Second, it provides one of the few comprehensive comparative analyses of climate change risk and financial sector development across the EMEA region. Third, the application of the PMG-ARDL estimator enables simultaneous estimation of long-run equilibrium relationships and heterogeneous short-run dynamics, thereby providing richer insights than conventional panel regression techniques.

Despite these contributions, several limitations should be acknowledged. The study focuses primarily on aggregate financial development indicators and does not explicitly consider individual banking sectors, insurance markets or capital market subsectors. Furthermore, climate change risk is measured using a composite climate risk index, which may not fully capture the diverse dimensions of physical and transition risks across countries. Future research may therefore examine specific financial sectors, incorporate alternative climate indicators and employ nonlinear or machine learning techniques to further explore the complex interactions between climate change and financial development.

Overall, the study demonstrates that climate change has become an important determinant of financial sector development. Building resilient financial systems capable of supporting sustainable economic growth under increasing climate uncertainty will require coordinated efforts involving governments, central banks, financial institutions and international development partners. Strengthening climate-responsive financial regulation, expanding sustainable finance and improving institutional resilience will be essential for ensuring long-term financial stability and sustainable development throughout the EMEA region.

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