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IMPACT OF CLIMATE CHANGE ON THE RESILIENCE OF THE BANKING SYSTEM:

THE CASES OF KAZAKHSTAN AND KYRGYZ REPUBLIC

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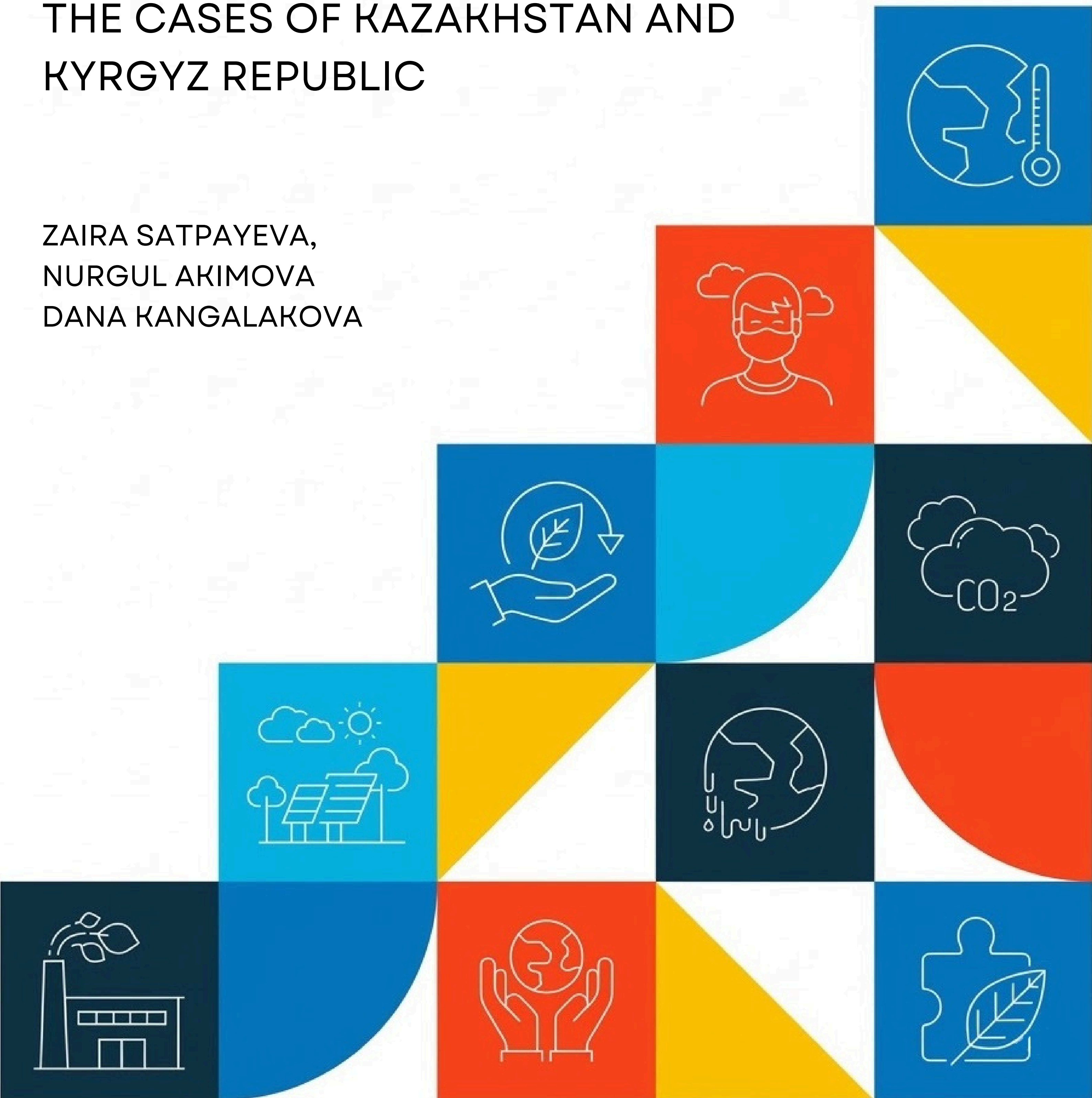

Impact of Climate Change on the Resilience of the Banking System: The Cases of Kazakhstan and Kyrgyzstan

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List of Acronyms and Abbreviations

Acronym	Full Form
AIFC	Astana International Financial Centre
BCBS	Basel Committee on Banking Supervision
CAR	Capital Adequacy Ratio
CAREC	Central Asia Regional Economic Cooperation
CPAT	Climate Policy Assessment Tool
ECB	European Central Bank
EPS	Earnings Per Share
ESG	Environmental, Social, and Governance
FX	Foreign Exchange
GDP	Gross Domestic Product
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
KR	Kyrgyz Republic
KZ	Republic of Kazakhstan
LCR	Liquidity Coverage Ratio
NGFS	Network for Greening the Financial System
NPL	Non-Performing Loan
OECD	Organisation for Economic Co-operation and Development
RCP	Representative Concentration Pathway
ROA	Return on Assets
ROE	Return on Equity
TCFD	Task Force on Climate-related Financial Disclosures
UNEP	United Nations Environment Programme
VAR	Vector Autoregression

Abstract

Climate change poses a multifaceted threat to financial stability, particularly in emerging economies. This study examines the impact of physical and transition climate risks on the banking systems of Kazakhstan and Kyrgyzstan. The analysis extrapolates historical data and projections through 2050, demonstrating that these risks directly affect credit portfolios by weakening credit quality and increasing default rates. Furthermore, the transition to a low-carbon economy generates transition risks, as rapid regulatory changes, carbon pricing, and shifts in investor sentiment can quickly devalue carbon-intensive assets and place pressure on the banking sector. The integrated methodological approach combines stress testing based on consolidated banking balance sheets, vector autoregression modeling, and an adapted Climate Policy Assessment Tool to forecast macroeconomic and financial dynamics under different physical and transition risk scenarios. The analysis spans through 2050 and simulates how capital adequacy, non-performing loans, and other key indicators respond to both gradual and sudden shocks. The findings suggest that current capital reserves may be sufficient to withstand moderate short-term disturbances. However, if physical risks intensify over time or a sudden transition shock occurs, many banks could face severe solvency challenges. These results focus the need to integrate climate risks into financial sector policies, develop green investment strategies, and adapt stress-testing tools to regional conditions.

Keywords: climate change, financial stability, banking system, stress testing, vector autoregression modeling, Central Asia.

1. Introduction

Global climate change presents the financial system with unprecedented challenges stemming from both physical risks (e.g., hurricanes, floods, and droughts) and transition risks (e.g., regulatory reforms, shifts in consumer behavior, and technological disruptions; Battiston et al., 2017; NGFS, 2020). As a central pillar of financial markets, the banking sector must adapt to these challenges, which require a reassessment of conventional risk assessment methodologies (Schuermann, 2013; Feyen et al., 2021).

Significant climate change is already observable in the Kyrgyz Republic and the Republic of Kazakhstan. The average annual temperature has risen by 1.2°C over the past 60 years (Jewell, 2023), a rate substantially higher than the global average. The increasing frequency of natural disasters, including floods, earthquakes, and landslides, has been shown to amplify physical risks and affect the financial stability of the banking system (United Nations Environment Program, 2025; World Bank, 2017). Consequently, climate-related shocks increase the probability of credit defaults and reduce asset values (Battiston et al., 2017; Klusak et al., 2021). These developments highlight the growing importance of specialized research in this field (Cardenas, 2024; Zhou & van der Ploeg, 2024).

Despite growing global recognition of climate-financial linkages, the banking systems of Kazakhstan and Kyrgyzstan remain only weakly integrated with climate risk considerations within prudential frameworks, stress-testing methodologies, and strategic planning processes. This research conducts a comparative assessment of climate-related vulnerabilities in the banking systems of these countries and develops evidence-based policy recommendations to enhance their resilience to physical and transition climate risks. In accordance with this objective, the study addresses the following research tasks:

1. Structural vulnerability analysis - Compare the structural characteristics of the banking systems, identifying country-specific exposure channels to climate risks through balance-sheet composition, sectoral concentrations, and macroeconomic linkages;

2. Transmission mechanism identification - Map the pathways through which physical and transition climate risks propagate through the banking system via credit quality, funding costs, and asset valuations;

3. Quantitative risk assessment - Implement integrated stress testing that combines vector autoregression (VAR) modeling of macroeconomic dynamics with climate scenario analysis,

projecting banking system performance under baseline and adverse climate-economic scenarios through 2050;

4. Critical threshold determination - Identify specific vulnerability thresholds and tipping points at which climate stresses could trigger systemic banking instability, thereby informing early-warning systems and intervention strategies; and

5. Policy framework development - Design differentiated prudential measures, supervisory practices, and regulatory reforms tailored to each country's climate-financial risk profile and institutional capacity.

The remainder of this paper is organized as follows. Section 2 provides a targeted literature review focusing on climate-finance linkages in emerging markets and identifying the specific gaps addressed by this study. Section 3 presents the integrated methodological framework, including detailed VAR model specifications, Climate Policy Assessment Tool (CPAT) adaptation procedures, and stress-testing implementation protocols. Section 4 reports empirical findings from the comprehensive stress-testing exercise, organizing results by risk type (physical vs. transition) and time horizon (short-, medium-, and long-term). The analysis emphasizes country-specific vulnerabilities and transmission mechanisms while maintaining comparability across scenarios. Section 5 translates the empirical findings into specific policy recommendations, providing implementation timelines, institutional requirements, and success metrics for each proposed measure. Section 6 concludes with an assessment of analytical limitations, directions for future research, and strategic implications for developing a climate-resilient financial system in Central Asia. Throughout the paper, the analysis maintains a focus on practical policy applications while acknowledging the inherent uncertainties in long-term climate-economic projections. This structure ensures direct correspondence between the stated research objectives, methodological implementation, empirical results, and policy recommendations, thereby strengthening study coherence while maintaining analytical rigor and policy relevance.

2. Literature Review

In recent decades, climate change has emerged as a significant macroprudential challenge for financial systems, particularly in developing countries that rely heavily on natural resources, such as Kyrgyzstan and Kazakhstan. Climate shocks encompass both direct physical risks (e.g., floods, droughts, and extreme weather events) and transition risks associated with increased regulation, technological shifts, and structural economic change (BOC Research Institute, 2024a; Jewell, 2023). These developments have the potential not only to compromise the quality of banks' loan portfolios but also to increase their operational vulnerability (BOC Research Institute, 2024b). In response, the use of green financial instruments has emerged as an important mechanism for reducing borrowing costs and stimulating investment in sustainable development (Caramichael & Rapp, 2022). The importance of such instruments continues to grow alongside accelerating climate and economic transformations.

The initial theoretical foundations of systemic resilience in banking institutions were established in the context of financial crises and macroeconomic shocks. Classic studies by Allen and Gale (2000) and Borio and Drehmann (2009) revealed mechanisms of shock transmission through financial assets and introduced the concept of the financial cycle, which has become central to the analysis of banking sector vulnerabilities. In the early 2000s, institutionalized approaches to stress testing began to emerge (CGFS, 2000), focusing on assessing the resilience of small open economies to macroeconomic shocks (Čihák, 2007). Over time, research attention shifted toward integrating macrofinancial models and developing multilevel stress tests that incorporate both economic and behavioral aspects of bank performance (Schuermann, 2013). These approaches were gradually institutionalized through the development of international regulatory standards (EBA, 2016; ECB, 2016), which contributed to the harmonization of risk assessment practices in global banking supervision.

Recognition of climate risks as a distinct category of systemic financial threats emerged in the mid-2010s. Seminal studies by the NGFS (2020), Klusak et al. (2021), and Gennaioli et al. (2010) demonstrated that both physical risks (e.g., natural disasters and droughts) and transition risks (e.g., decarbonization policies and the declining value of carbon-intensive assets) can significantly affect financial stability. In the context of Kazakhstan and Kyrgyzstan, banks remain highly vulnerable to such shocks, even under conditions of formal compliance with the Paris Agreements. Contemporary theoretical studies have further examined the interaction between climate hazards and economic systems (Zhou & van der Ploeg, 2024), emphasizing the sensitivity of the social cost of carbon and the climate risk premium to structural changes in the economy.

Empirical evidence from the Atlas of Environmental Change (UNEP, 2025) has documented significant increases in temperature, shifts in precipitation patterns, and growing water scarcity. These environmental changes negatively affect key economic sectors and weaken banking sector resilience. To address these challenges, scenario-based stress tests and climate-adapted macrofinancial models are increasingly being implemented (Zhou & van der Ploeg, 2024; UNEP, 2025). Such approaches enable the simulation of the financial consequences of extreme weather events and abrupt temperature changes, allowing the identification of potential losses within financial institutions. The integration of climate considerations into bank risk management frameworks has progressed alongside international regulatory initiatives. Institutions such as the Basel Committee, the European Central Bank (ECB), and the Organization for Economic Cooperation and Development have introduced standards requiring the incorporation of climate risks into financial supervision and stress testing (OECD, 2018, 2023; IMF, 2023). Similarly, green bonds and specialized credit lines are increasingly used to mobilize investment in sustainable projects. Governments also support these efforts through tax incentives, guarantees, and direct financing programs that reduce the capital costs associated with sustainable innovation.

In recent years, research has increasingly emphasized institutional adaptation, transparency, and collective mechanisms for responding to climate threats. Studies by Ciullo et al. (2022), Feyen et al. (2021), the World Bank Group and the Asian Development Bank (2021), the U.N. Office for Disaster Risk Reduction and the World Meteorological Organization (2023), and the U.N. Development Program (2022) have highlighted the importance of regional catastrophe insurance funds, risk-pooling mechanisms, environmental, social, and governance (ESG) disclosure systems, and the integration of climate information into macroeconomic planning and budgetary processes. A growing body of research has also stressed the need to develop climate data infrastructure to support policy design and financial decision-making in countries with limited institutional capacity.

Despite these advances, the literature continues to reveal significant gaps. In particular, there is a lack of nationally calibrated climate-financial models for post-Soviet economies, limited availability of sector-specific climate data, insufficient integration of climate risks into banking supervision frameworks, and weak cross-border coordination in addressing transnational climate risks (Cardenas, 2024; Schuermann, 2013). Moreover, a comprehensive evaluation of water resource risks, migration dynamics, and infrastructure vulnerabilities specific to Central Asia remains largely absent from existing research. Table 1 summarizes the key studies informing this research.

Table 1: Literature Review Summary

Author	Purpose	Methodology	Main Findings
Allen and Gale (2000)	Examine contagion in banking crises	Theoretical network equilibrium model	Network structures can propagate local shocks into systemic crises

Author	Purpose	Methodology	Main Findings
Basel Committee (2013)	Strengthen liquidity regulation	LCR regulatory framework	Liquidity rules increase banking resilience
Battiston et al. (2017)	Develop climate–financial stress test	Transition-risk scenario modeling	Delayed decarbonization leads to systematic losses
Borio and Drehmann (2009)	Identify banking crisis indicators	Panel analysis of credit and asset prices	Financial cycle predicts systemic risks
Cardenas (2024)	Review financial climate risk frameworks	Regulatory and model synthesis	Central banks play a key role in climate supervision
CGFS (2000)	Survey stress-testing practices	Institutional survey	Practices remain fragmented
Čihák (2007)	Introduce stress-testing principles	Scenario-based empirical analysis	Stress tests must incorporate multiple risk channels
Čihák and Ong (2010)	Improve liquidity stress testing	Stress-scenario modeling	Ignoring behavioral effects reduces test accuracy
Ciullo et al. (2022)	Analyze catastrophic risk pooling	Loss modeling and pool comparison	Global pools reduce costs and increase resilience
Demekas (2015)	Assess macroprudential stress tests	Model and behavioral responses analysis	Agent-based models improve stress testing
EBA (2016)	Standardize default definition	Regulatory guidance development	Harmonized definitions improve supervisory comparability
Feyen et al. (2021)	Review macrofinancial climate risks	Literature review and policy analysis	Institutional gaps hinder climate risks integration
Gennaioli et al. (2022)	Compare climate risk perception	Portfolio-based empirical analysis	Banks underestimate climate risks
Klusak et al. (2021)	Assess climate effects on sovereign ratings	Panel regression across 108 countries	2–3 °C warming lowers ratings in developing countries
NGFS (2020)	Develop climate risk scenarios	Physical and transition scenario modeling	Long-term financial impacts requiring policy integration
OECD (2024)	Evaluate ESG disclosure effects	Comparative disclosure analysis	Standardized reporting reduces financial risks
Schuermann (2013)	Evaluate stress-testing practices	Comparative central bank analysis	Network risks often underestimated
UNDP (2022)	Assess macro-fiscal climate risks	Fiscal modeling scenarios	Climate integration improves fiscal resilience
UNDRR and WMO (2023)	Guide climate data use	Risk management framework	Climate data enhances stress-test accuracy
Vermeulen et al. (2018)	Evaluate energy transition risks	Asset-revaluation scenario analysis	Financial institutions exposed to carbon-asset revaluation
World Bank (2017)	Assess sovereign risk pooling	Policy modeling	Risk pools strengthen resilience in vulnerable economies

Consequently, scientific perspectives have evolved from early theories of financial shocks toward recognizing climate change as a central factor in systemic financial resilience. Contemporary approaches emphasize the implementation of ESG practices, improved climate stress testing, collective insurance mechanisms, and the development of climate information infrastructure. In the context of the banking systems of Kazakhstan and Kyrgyzstan, integrating climate risks into management strategies is therefore essential for maintaining financial stability in the medium term. Accordingly, the research hypothesis of this study suggests that climate change affects the resilience of the banking systems of Kazakhstan and Kyrgyzstan, and the nature and magnitude of this impact differ between the countries.

3. Methodology

This section outlines the methodological framework used to evaluate the resilience of the banking sectors in Kyrgyzstan and Kazakhstan under macroeconomic and climate-related stress. The study adopts a quantitative approach that integrates econometric modeling, stress-testing techniques, and sensitivity analysis. Data processing and simulations were conducted using Microsoft Excel v.16.0, with projections extending from historical baselines (2005-2024) to 2050.

3.1 Research Design

The research design employs a four-module stress-testing framework aligned with the CPAT architecture, progressing from preliminary macroeconomic trend analysis to climate-integrated simulations. This sequential structure enables scenario calibration based on empirical trends while maintaining consistency with established protocols from the Basel Committee on Banking Supervision (BCBS, 2018) for conventional stress testing and the Network for Greening the Financial System (NGFS, 2021) for climate risk scenarios.

Four interconnected modules were implemented:

1. Simple direct shocks: Static balance-sheet stress tests;
2. Conventional macroeconomic-linked tests: VAR-based projections to 2026;
3. Macro physical risk assessments: Long-term climate impact modeling to 2050; and
4. Micro transition risk evaluations: Sectoral carbon pricing scenarios to 2027.

3.2 VAR Modeling Specification

The VAR model was specified to capture dynamic interactions between macroeconomic variables and banking sector indicators. The baseline VAR(2) specification included five endogenous variables for each country:

- For Kyrgyzstan: Non-performing loan (NPL) ratio (p_t), gross domestic product (GDP) deflator growth (yg_t), remittances as % of GDP (u_t), deposit interest rate (i_t), and FX depreciation rate (dep_t); and
- For Kazakhstan: NPL ratio (p_t), GDP deflator growth (yg_t), oil price growth (oil_t) replacing remittances, deposit interest rate (i_t), and FX depreciation rate (dep_t).

3.3 Climate Variables

Climate variables were incorporated following the NGFS (2020) methodology, establishing scenario-based linkages between temperature anomalies, precipitation changes, and macroeconomic variables through empirically derived elasticities. Specifically, temperature anomalies and precipitation changes were linked to macroeconomic outcomes through the following relationships: 1°C warming → 2.5% GDP reduction (physical channel) and carbon tax equivalents → sectoral NPL adjustments (transition channel).

Linking macroeconomic variables to climate-induced shocks enables identification of the transmission channels through which environmental stress affects banking stability. This specification operationalizes the conceptual framework by capturing country-specific propagation mechanisms - remittance volatility and fiscal dependence in Kyrgyzstan, and commodity price dynamics and stranded-asset risks in Kazakhstan. Accordingly, the VAR model is not purely statistical but structurally grounded in the institutional and macroeconomic characteristics of each economy.

3.4 Country-Specific Calibration and Critical Thresholds

Preliminary analysis identified distinct vulnerability transmission mechanisms for each country:

Kyrgyzstan: Primary channel: remittance volatility → FX pressure → import inflation → debt service stress, secondary channel: migration disruption → labor shortages → agricultural productivity decline, and tertiary channel: external aid dependency → fiscal stress → banking sector exposure.

Kazakhstan: Primary channel: commodity price volatility → FX earnings → fiscal revenues → banking liquidity; secondary channel: energy transition → stranded assets → corporate defaults → NPL increases; tertiary channel: Dutch disease effects → reduced competitiveness of the non-oil sector → credit demand contraction.

Critical regulatory and systemic thresholds were established using three benchmarks:

1. Regulatory minima: cumulative abnormal return (CAR) < 8% (Basel III), NPL > 5% (FSI guidelines);

2. Historical crisis indicators: Z-score < 10; and

3. Country-specific stress points: Kyrgyzstan's remittance decline > 30%, Kazakhstan's oil price drop > 40%.

Table 2 summarizes the transmission channels and VAR variable mapping.

Table 2: Transmission Channels and VAR Variable Mapping

Transmission Channel	Kyrgyzstan (Variable)	Kazakhstan (Variable)	Type of Risk
External demand shock	Remittances (% GDP)	Oil prices (USD / barrel)	Physical / Macro
Exchange rate pass-through	FX depreciation rate	FX depreciation rate	Financial
Inflationary channel	GDP deflator growth	GDP deflator growth	Physical
Credit risk propagation	NPL ratio	NPL ratio	Financial
Fiscal linkage	External aid dependence	Fiscal revenues (oil-linked)	Transition
Asset revaluation	-	Stranded-asset value	Transition

Note: This table lists the structural correspondences among macroeconomic variables and transmission mechanisms. The VAR configuration is calibrated to capture country-specific climate-induced financial stress.

3.5 Scenario Construction and Stress-Testing Implementation

The three physical risk scenarios aligned with IPCC pathways included:

- Baseline (RCP 4.5): 2°C warming by 2050 with moderate precipitation changes;

- Moderate stress (RCP 6.0): 3°C warming with increased drought frequency; and

- Severe stress (RCP 8.5): 4°C warming with intensified extreme weather.

Transition risk scenarios were based on alternative carbon pricing trajectories:

- Delayed transition: carbon price reaches USD 50/tCO_2 by 2030;
- Accelerated transition: carbon price reaches USD 100/tCO_2 by 2027; and
- Disorderly transition: sudden implementation of USD 150/tCO_2 by 2025.

Under the RCP 8.5 scenario, extreme CAR and NPL values (e.g., CAR = −229.8% for KR; NPL = 101.5% for KZ) appear as diagnostic thresholds representing systemic tipping points rather than probabilistic forecasts. These magnitudes arise from cascading effects, including compound interactions among drought-driven agricultural losses, remittance shocks, and simulated hyperinflation (GDP deflator ≈ 200%). The model is designed to detect nonlinear breakpoints in systemic fragility, where the banking system shifts from resilience to collapse.

3.6 Analytical Limitations

The analysis was limited by a lack of granular bank-level data, reflecting system-wide aggregation. Additionally, the short historical time series for climate–finance linkages (2005-2024) and assumption-based sectoral loan exposure was limiting due to unavailable portfolio breakdowns.

In terms of methodology, the assumption of parameter stability over a 25-year projection horizon was limiting, leading to potential structural breaks. Additionally, presumed linear relationships may have led to an underestimation of nonlinear climate impacts. Furthermore, VAR framework limitations may have led to failure in capturing tail-risk events and regime shifts.

Regarding model uncertainty, sensitivity analysis bounds may not have fully captured parameter uncertainty, and cross-country spillover effects were not modeled, despite regional economic integration. Moreover, behavioral responses such as bank adaptation or regulatory changes were not endogenized.

These limitations are partially mitigated through extensive sensitivity analysis and conservative interpretation of long-term projections, with policy conclusions focused primarily on near-term outcomes (2026-2030).

The application of the CPAT framework and NGFS-aligned IPCC scenarios (RCP 4.5, 6.0, and 8.5) followed internationally recognized standards for climate-financial risk analysis. This alignment ensures methodological comparability with global climate stress-testing exercises, including those conducted by the IMF and the ECB. Although national data limitations remain, the use of standardized scenarios improves transparency and facilitates cross-country comparability. The use of aggregate banking data, while restrictive, remains analytically appropriate for evaluating systemic vulnerabilities in emerging markets, as it captures the primary macrofinancial transmission effects.

4. Results and Discussion

4.1 Structural Vulnerability Assessment

The monetary policy frameworks of Kazakhstan and Kyrgyzstan differ in ways that influence the resilience of their banking sectors. The following subsections correspond to the five research objectives introduced earlier. Throughout each, the empirical analysis addresses structural vulnerabilities, transmission mechanisms, and quantitative climate-related stress effects on key financial soundness indicators.

Research Task 1 examines the structural characteristics of the two banking systems to identify country-specific exposure channels to climate risks. Kazakhstan experienced subsantial currency depreciation, with the tenge reaching 468.96 per USD in 2024, while Kyrgyzstan recorded a more moderate devaluation to 87.15 som per USD. Inflation peaked at 15.03% in Kazakhstan and 13.92% in Kyrgyzstan in 2022, reflecting both countries' sensitivity to external shocks. Notably, external sector stability differs significantly between the two economies. Kazakhstan maintains foreign reserves equivalent to 5.49 months of imports (2024), providing a substantial buffer against external disturbances. Kyrgyzstan's reserves cover 3.07 months of imports (2022), meeting minimum adequacy thresholds but offering more limited shock-absorption capacity. Personal remittances account for 18.77% of GDP in Kyrgyzstan (2023), creating systemic vulnerability to disruptions in migration flows, whereas Kazakhstan's dependence on remittances remains negligible (0.08% of GDP).

Kyrgyzstan's banking sector exhibits considerable liquidity volatility, with liquid reserves-to-assets ratios ranging from 5.4% to 43.0%, indicating episodes of financial stress followed by stabilization measures. Bank capital-to-assets ratios remain relatively stable at 12-18% in Kyrgyzstan and slightly higher in Kazakhstan, both broadly consistent with international capital adequacy standards.

The liquidity shocks observed in Kyrgyzstan and Kazakhstan indicate distinct transmission mechanisms for climate and macroeconomic disturbances. In Kyrgyzstan, vulnerability is transmitted primarily through remittance volatility and dependence on external aid. In Kazakhstan, the dominant transmission channel operates through fluctuations in global oil prices and the valuation of carbon-intensive assets. These findings support the hypothesis of structurally different financial propagation channels between the two economies.

Kyrgyzstan experienced a sharp contraction in private-sector credit from 58.9% of GDP to 25.8%, suggesting credit tightening or structural shifts in the banking sector that warrant further investigation. Non-performing loans reached 20.9% in 2010 before declining as a result of banking sector rehabilitation efforts.

Banking density differs substantially between the two systems. Kyrgyzstan maintains approximately 8-12 bank branches per 100,000 adults, compared with 15-20 in Kazakhstan, reflecting differences in financial inclusion. Interest rate spreads average 8-12% in Kyrgyzstan but only 5-8% in Kazakhstan, indicating variations in competitive conditions and risk management practices.

Capital market infrastructure remains underdeveloped in both economies. Market capitalization-to-GDP ratios remain below 5% in Kyrgyzstan and range between 15% and 35% in Kazakhstan. Both markets exhibit limited liquidity, with stock turnover ratios below 1% in Kyrgyzstan and between 2% and 8% in Kazakhstan. These constraints limit alternative financing channels and increase reliance on bank-based financial intermediation.

Government debt trajectories also differ and affect banking sector exposure. Kyrgyzstan's debt-to-GDP ratio increased from 43.7% in 2010 to 64.8% in 2024, approaching the 70% sustainability threshold commonly applied to emerging markets. Kazakhstan maintains lower debt levels between 24.1% and 33.7% of GDP, providing stronger fiscal buffers and reducing sovereign risk exposure for domestic banks.

External debt composition creates additional differences in vulnerability. In Kyrgyzstan, external liabilities account for 76.3% of total government debt, exposing the economy to exchange-rate and global interest-rate risks. Kazakhstan's more balanced structure, with 52.6% external debt, reduces currency-mismatch risks.

Kazakhstan's relatively high energy intensity (0.4–0.5 tons of oil equivalent per $1,000 of GDP) and carbon emissions (1.2–1.5 kg CO_2 per GDP dollar) reflect a carbon-intensive economic structure, creating potential stranded-asset risks for bank lending portfolios. Kyrgyzstan's lower energy intensity (0.2–0.3

tons of oil equivalent per $1,000 of GDP) and emissions (0.4–0.6 kg CO_2 per GDP dollar) indicate comparatively lower direct transition risk.

Both economies also face transboundary water-management challenges under climate change. Kyrgyzstan's role as a regional water source creates systemic risks linked to glacial degradation and shifts in the hydrological regime. Kazakhstan, by contrast, faces increasing water scarcity—particularly in southern regions—potentially constraining agricultural and industrial sectors and affecting bank loan portfolios.

Institutional indicators reveal differences in regulatory environments that shape the effectiveness of banking supervision. Kazakhstan ranks higher in regulatory quality (60–70%) and government effectiveness (65–75%) than Kyrgyzstan (40–55%), indicating stronger supervisory capacity to address climate-related financial risks.

Innovation capacity remains limited in both countries. Research and development expenditure ranges between 0.15% and 0.2% of GDP in Kazakhstan and remains below 0.1% in Kyrgyzstan, constraining the development of green finance instruments and climate-adaptation technologies.

4.2 Quantitative Stress Testing Results

Research Task 3 implements integrated stress testing to project banking system performance under baseline and adverse climate-economic scenarios through 2050.

4.2.1 Banking System Balance Sheets

Stylized balance sheets were constructed to establish 2024 baselines. In Kyrgyzstan, total banking assets reached 815,587.5M som, with net loans representing 40% (325,322.3M som) and a capital-to-assets ratio of 76.7%. Pre-shock financial soundness indicators included a CAR of 39.3%, an NPL ratio of 0.81%, provisions coverage of −1,209.4%, return on assets (ROA) of 21.9%, return on equity (ROE) of 28.5%, a liquidity ratio of 26.5%, a net FX position-to-capital ratio of 0.001%, and a Z-score of 32.8. Capital VAR was estimated at −61,471.5M som (−6.4% of capital), assuming 3% asset volatility.

In Kazakhstan, total banking assets reached 54,852,396M tenge, with net loans accounting for 17% (9,527,409M tenge). The simulated capital-to-assets ratio was −21.3%, indicating structural undercapitalization in the modeled baseline. Financial soundness indicators included a CAR of −2.8%, an

NPL ratio of 101.3%, provisions coverage of 0.15%, ROA of 369.0%, ROE of −1,735.5%, a net FX position-to-capital ratio of −644.2%, and a Z-score of 115.9. Capital VAR reached −2,706,725M tenge (23.2% of capital).

At this stage, the unusually high NPL ratio (101.5%) and negative CAR (−2.8%) should not be interpreted as model instability. Instead, they represent simulated structural fragilities - particularly legacy NPL accumulation and historical undercapitalization in the Kazakh banking system. These values therefore function as diagnostic baselines illustrating systemic fragility thresholds rather than predictive outcomes.

Overall, the baselines indicate Kyrgyzstan's stronger liquidity position but moderate foreign-exchange exposure, whereas Kazakhstan exhibits greater market exposure combined with legacy NPL vulnerabilities.

4.2.2 Simple and Conventional Stress Tests

Under adverse shocks (+25% NPLs, −10% securities valuation, and +25% FX depreciation) projected to 2050, Kyrgyzstan's CAR increased to 426.9% (from 39.3%), the NPL ratio reached 0.76%, net NPLs-to-capital rose to 0.98%, and the net FX position-to-capital ratio declined to −1.5%. In Kazakhstan, CAR increased to 19.1% (from −2.8%), the NPL ratio rose to 126.6%, net NPLs-to-capital reached 14.9%, and the net FX position-to-capital ratio increased to 116.2%.

Macro-linked projections to 2026 under stress conditions (e.g., +2.89% in the GDP deflator and 9.4% FX depreciation) resulted in Kyrgyzstan's CAR declining to −229.8%, the NPL ratio rising to 42.0%, net NPLs-to-capital increasing to 243.4%, and ROA falling to −19.5%. In Kazakhstan, CAR declined to 14.9%, the NPL ratio increased to 23.9%, and net NPLs-to-capital reached −4.5%.

This set of results directly addresses Research Task 3 by quantifying how physical and transition shocks affect capital adequacy and asset quality. The pronounced divergence between Kyrgyzstan's sensitivity to external demand shocks and Kazakhstan's exposure to commodity price volatility illustrates the heterogeneity of climate-financial transmission channels in small open economies.

These quantitative outcomes confirm Research Task 3 by demonstrating that under extreme climate scenarios (RCP 8.5), bank capital in Kyrgyzstan declines more sharply than in Kazakhstan. This result reflects the greater elasticity of financial indicators to external shocks in remittance-dependent economies. The stress-test findings therefore provide quantitative support for the study's hypothesis regarding differentiated mechanisms of climate risk transmission across the two banking systems

4.2.3 Adverse Macro Scenarios

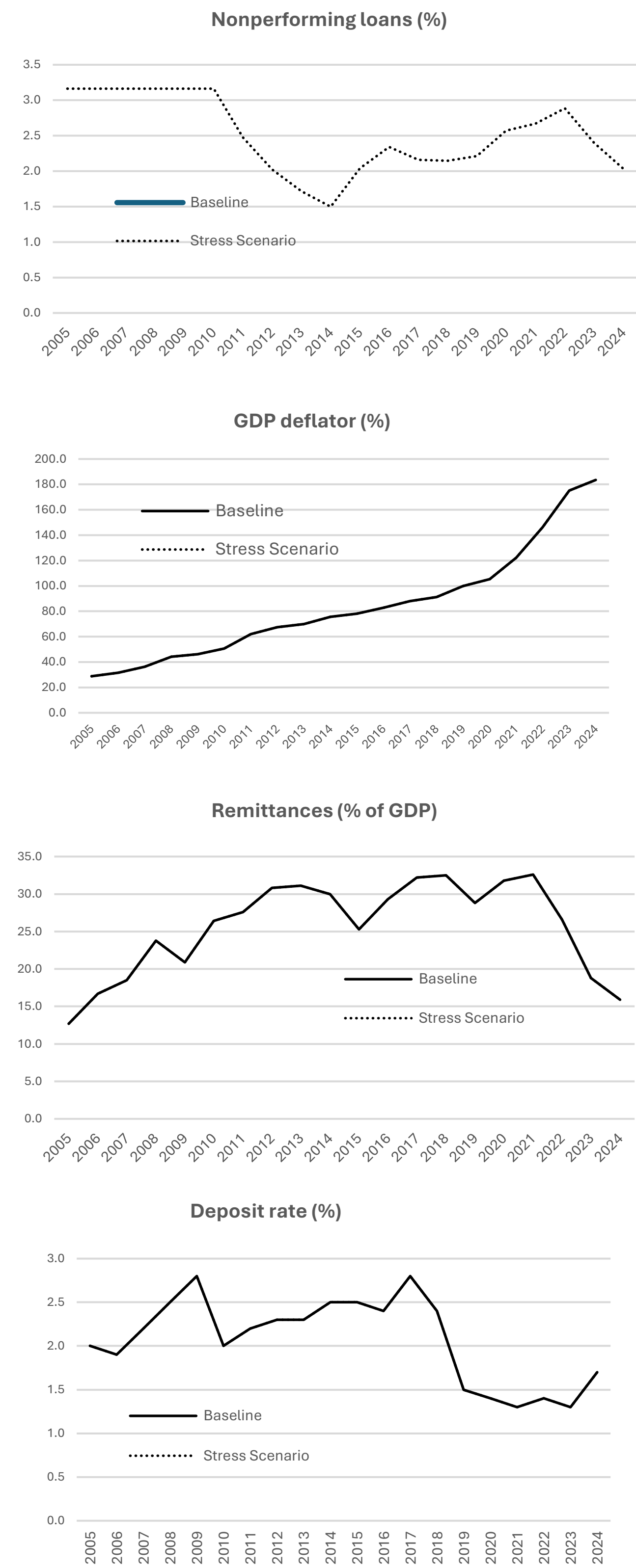
Kyrgyzstan's banking system displays dynamics that differ markedly from those of Kazakhstan. The baseline Capital/RWA ratio is 23.7%, consistent with international standards and indicative of adequate capitalization.

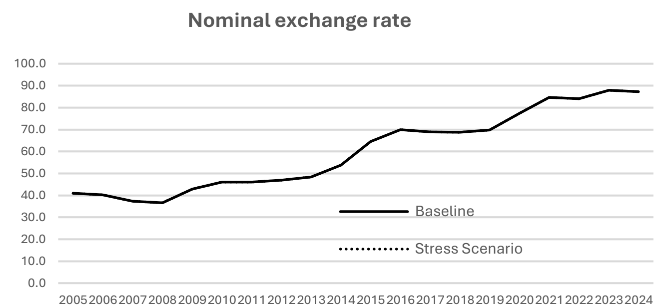
A key difference emerges in the response to stress conditions. Under the adverse macroeconomic scenario, the Capital/RWA ratio falls sharply to −229.8% by 2026, indicating the Kyrgyz banking system's high vulnerability to external shocks and macroeconomic instability. Long-term projections indicate recovery to 426.9% by 2050, suggesting the system's potential to adapt to long-term climate-related pressures.

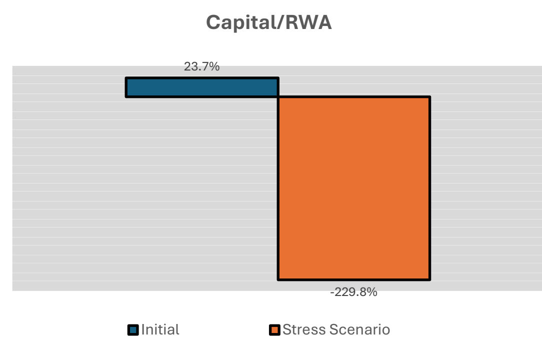
Kyrgyzstan's credit portfolio quality is initially stable. The baseline NPL/Gross Loans ratio is 0.9%, consistent with international benchmarks and indicative of effective credit risk management. Under the stress scenario, this ratio increases to 42.0%, which, although substantial, remains within the modeled system's absorption capacity.

The empirical findings illustrated in Figure 1 indicate a critically weak capital position in the Kyrgyzstani banking sector at the baseline level.

Figure 1: Kyrgyzstan: Adverse Macro Scenario and Impact on Banking System Balance Sheet







The Capital/RWA ratio stands at -2.8% in 2024, reflecting a substantial capital deficit relative to risk-weighted assets. This result signals a significant threat to financial system stability. These values should be interpreted as diagnostic thresholds of systemic fragility rather than baseline forecasts.

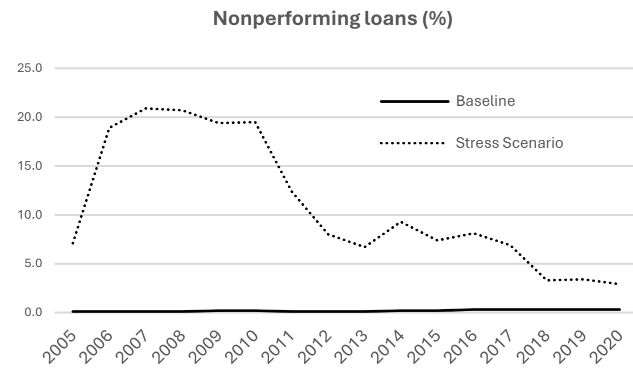
The modeling reveals notable dynamics under different stress scenarios. Within the conventional stress-testing framework, the Capital/RWA ratio improves by +23.7% by 2026, suggesting potential short-term recovery in the system's capital position. The most pronounced changes appear under the long-term physical climate risk scenario, where Capital/RWA may reach +19.1% by 2050, indicating a fundamental restructuring of the capital base.

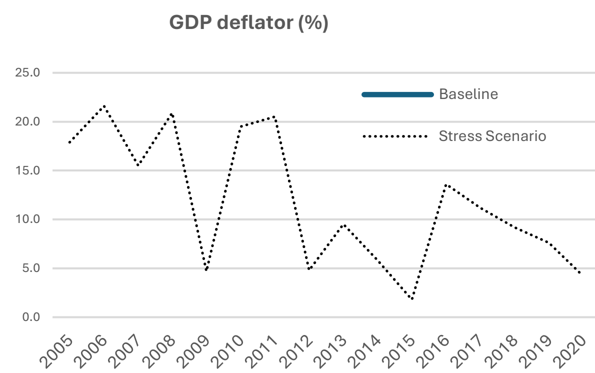
Asset quality indicators reveal extremely high levels of non-performing loans. The baseline NPL/Gross Loans ratio is 101.5%, far exceeding international benchmarks and indicating a systemic lending crisis. Under the stress scenario, this indicator rises further to 126.6%, pointing to a deepening credit crisis.

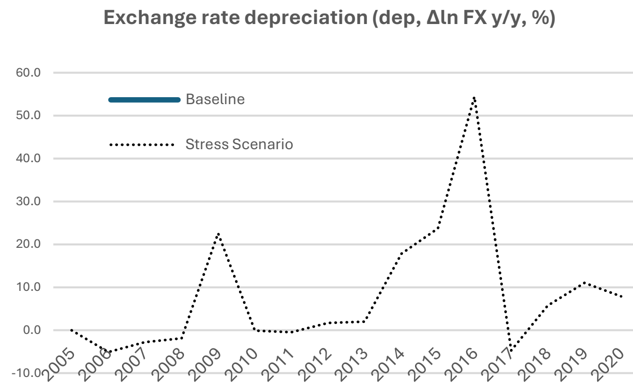
The ratio of net non-performing loans to capital reveals additional structural weaknesses. The initial value of −2.8% shifts to +14.9% by 2050, suggesting a gradual normalization of the relationship between problem assets and capital over the long term.

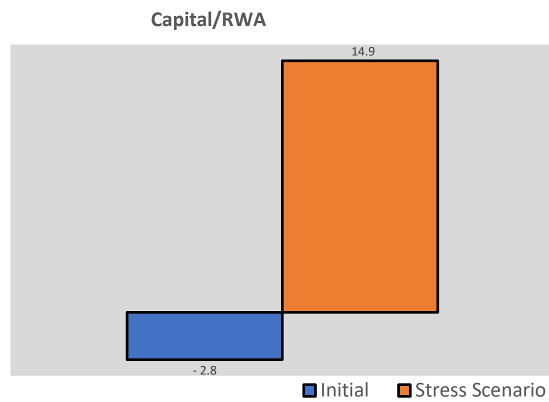
The comparative analysis illustrated in Figure 2 reveals fundamental differences in the capital structures of the two banking systems.

Figure 2: Kazakhstan: Adverse Macro Scenario and Impact on Banking System Balance Sheet









Kyrgyzstan reflects a conventional stability model characterized by adequate initial capitalization. In contrast, Kazakhstan begins with a capital deficit, which may reflect more aggressive lending practices or deeper structural economic challenges.

The two banking systems exhibit opposite responses to short-term stressors. Kazakhstan's system shows improvement in several indicators under stress conditions, potentially indicating restructuring or "cleansing" effects. By contrast, Kyrgyzstan's banking sector displays a conventional stress response, marked by a sharp deterioration in capital indicators.

Analysis of GDP deflator dynamics highlights substantial differences in inflationary processes under stress scenarios. Kyrgyzstan exhibits exponential growth in the GDP deflator, reaching peak values of approximately 200% by 2024, suggesting the possibility of hyperinflation. Kazakhstan's inflation dynamics remain comparatively stable, with moderate fluctuations in the range of 5-25%.

Exchange-rate dynamics also demonstrate differing degrees of currency vulnerability to external shocks. The Kazakhstani tenge shows high volatility, with depreciation peaking at approximately 55% in 2016-

2017 under the stress scenario, while remaining relatively stable under the baseline scenario. The Kyrgyz som follows a more stable trajectory, characterized by gradual depreciation rather than abrupt spikes.

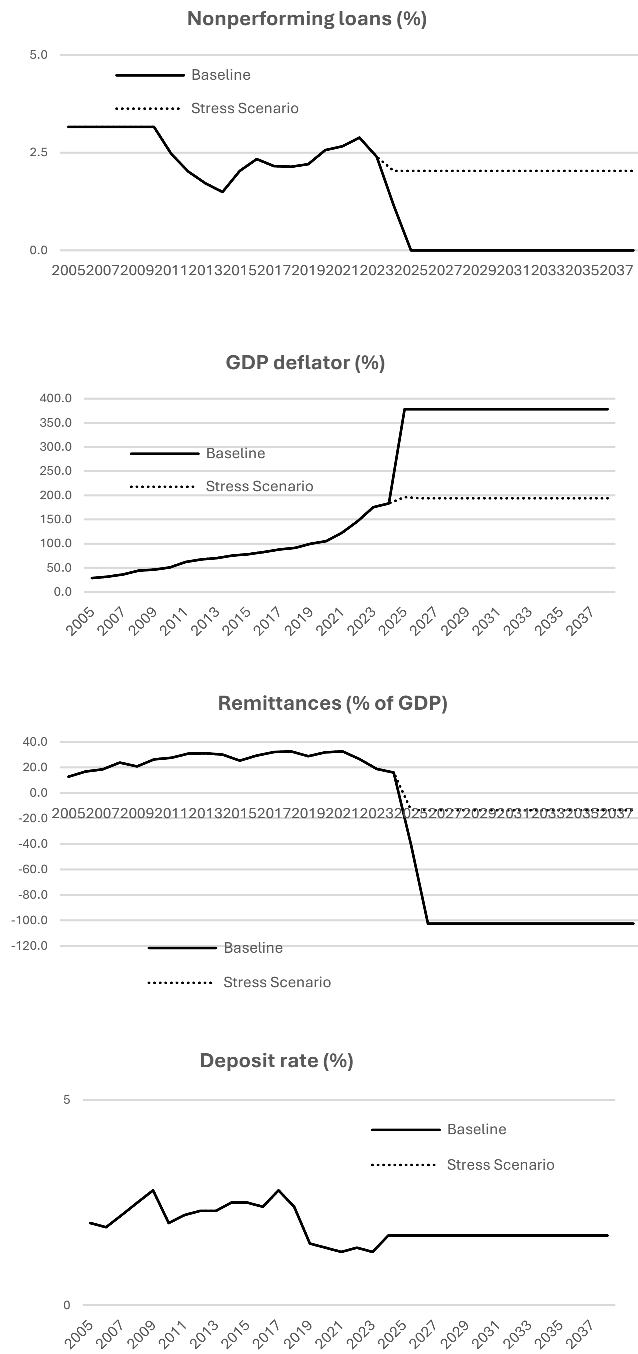
Deposit rate dynamics reflect adaptive monetary policy responses to macroeconomic shocks. In Kyrgyzstan, deposit rates decline from 2.8% to 1.5% by the end of the projection period, potentially reflecting a stimulative policy stance. Kazakhstan's deposit rates remain more stable, fluctuating around 2.0-2.5%.

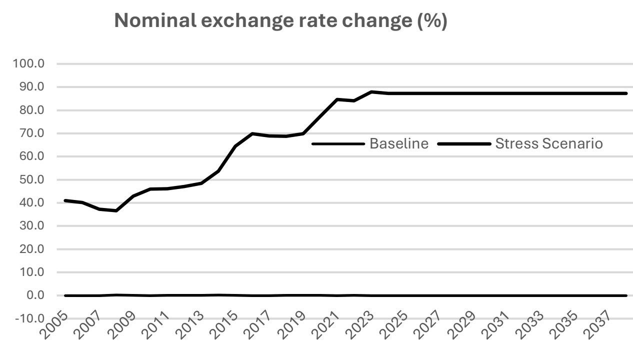
4.2.4 Physical Risk Scenarios

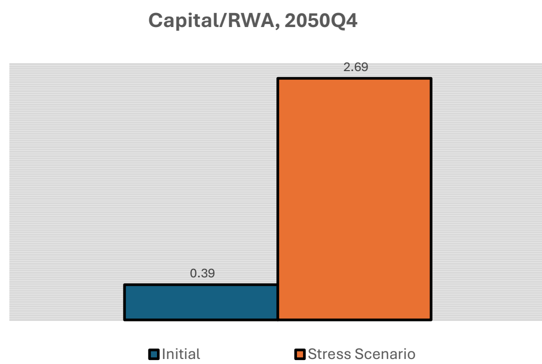
Chronic climate risks projected to 2050 (stress parameters: NPL +24.43%, deposit rate +8.8%, FX depreciation +5.25 log points) yield a projected CAR of 269.4% for Kyrgyzstan, with an NPL ratio of −1.0% and securities devaluation of −5.1%. In Kazakhstan, the corresponding projections indicate a CAR of 228.2%, an NPL ratio of 28.3%, and securities devaluation of −26.6%.

Figure 3 illustrates the projected effects of chronic physical climate risks (e.g., rising temperatures and natural disasters) on Kyrgyzstan's banking system balance sheet under baseline and stress scenarios from 2024 to 2050.

Figure 3: Kyrgyzstan: Physical Risk Scenario and Impact on Banking System Balance Sheet





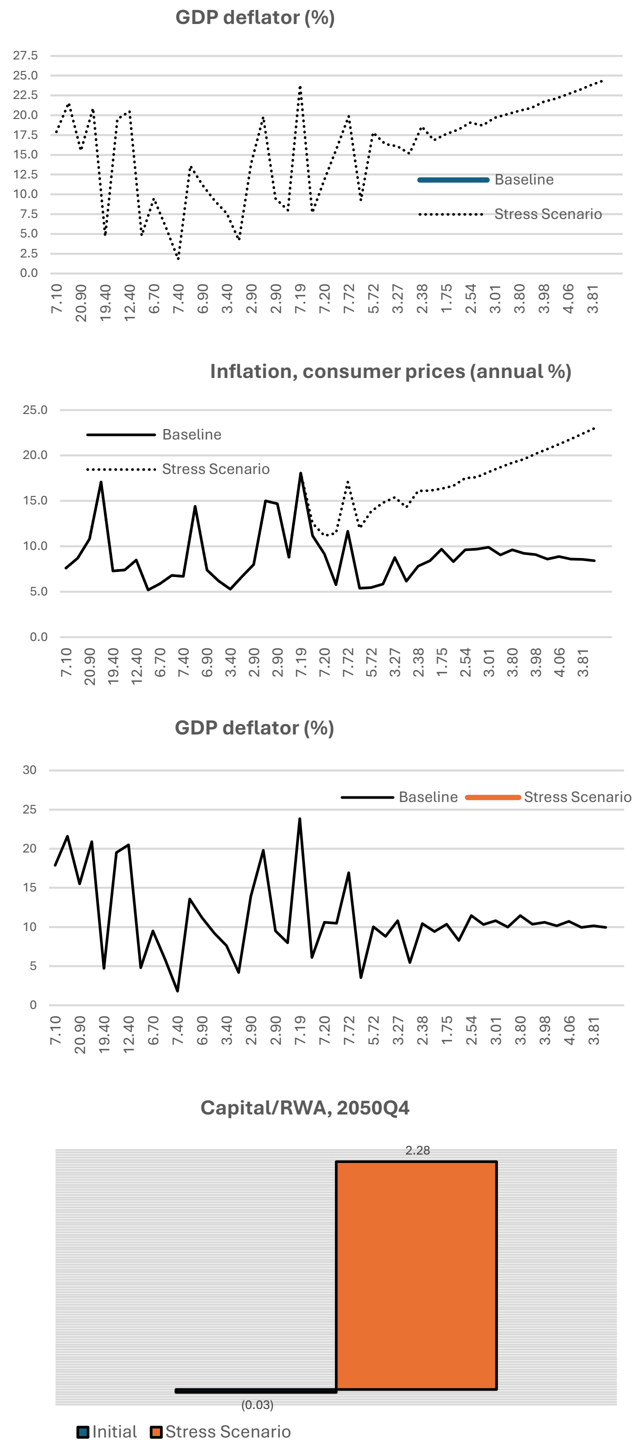


The left panel compares asset compositions, showing total assets increasing from 815,587.5M som in 2024 to 1,386,498.75M som in 2050 under baseline conditions. Over the same period, net loans decline to 189,305.3M som due to rising non-performing loans (from 1,945.3M som to a stressed impairment level of −1.04%). On the liabilities side, deposits increase to 813,359.5M som, although capital weakens under stress conditions, with the CAR declining to 269.4

The right panel highlights key balance sheet adjustments: a −5.1% devaluation of the securities portfolio due to duration effects (D = 3), a +5.25 log-point FX depreciation, and a −1.0% shift in the NPL ratio. The bar charts compare pre- and post-shock ratios, illustrating measurable deterioration in capital indicators under severe physical risk scenarios.

Figure 4 illustrates the effects of chronic physical climate risks on Kazakhstan's banking system balance sheet under baseline and stress scenarios from 2024 to 2050.

Figure 4: Kazakhstan: Physical Risk Scenario and Impact on Banking System Balance Sheet



The left panel shows the evolution of assets: total assets increase from 54,852,396M tenge in 2024 to 1,059,045,153M tenge in 2050 under the baseline scenario, while net loans stabilize at 9,537,921M tenge despite rising NPL pressures (from 9,666,942M tenge to a stressed increase of 26.97%). On the liabilities side, deposits rise to 4,457,922M tenge, while capital improves, resulting in a projected CAR of 228.2%.

The right panel quantifies key balance-sheet effects: a −26.6% devaluation of securities using the duration formula (D = 3), deposit rate increases of +8.8%, and an NPL ratio rising to 28.3%. The bar charts compare pre- and post-shock ratios, showing a 2.7% adjustment in the net NPLs-to-capital ratio under stress and highlighting Kazakhstan's greater exposure associated with its resource-intensive economic structure.

Structural analysis of banking assets reveals fundamental differences in banking models. Kazakhstan's system is dominated by liquid assets with a relatively small credit portfolio, whereas Kyrgyzstan shows a more balanced structure with a larger share of lending relative to total assets.

Analysis of liability structures reveals important differences in funding sources. Kazakhstani banks display an unusual structure characterized by negative capital and a large share of other liabilities. Kyrgyz banks maintain a more conventional structure with stronger capital positions and a predominance of customer deposits.

Research Task 2 maps the pathways through which physical and transition climate risks propagate through each banking system. Econometric modeling indicates that the elasticity of bank credit relative to GDP equals 3.0 in both countries, demonstrating high sensitivity of lending to macroeconomic fluctuations. This coefficient exceeds typical values for developed economies and indicates stronger cyclicality in the regional banking sector.

This elasticity value (3.0) represents a critical structural link in the transmission mechanism: a 1% decline in GDP caused by a climate-related shock is associated with approximately a threefold deterioration in credit portfolio quality. The magnitude highlights the amplification effect of macroeconomic volatility on banking system stability and operationalizes the "shock–macro–bank" transmission sequence. It also confirms that the VAR specification captures realistic propagation dynamics rather than a purely statistical relationship.

Credit portfolio stress-testing results reveal clear differences in shock resilience. Kyrgyzstan shows a projected deterioration in credit portfolio quality of −19.5%, whereas Kazakhstan's comparable indicator is −8.3%. These outcomes indicate greater vulnerability of the Kyrgyz banking system to macroeconomic instability.

The analysis identifies key systemic vulnerabilities in both banking sectors. In Kazakhstan, the main risk stems from structural imbalances in capitalization, reflected in negative capital adequacy ratios. This condition creates a potential pathway to systemic banking instability under adverse scenarios.

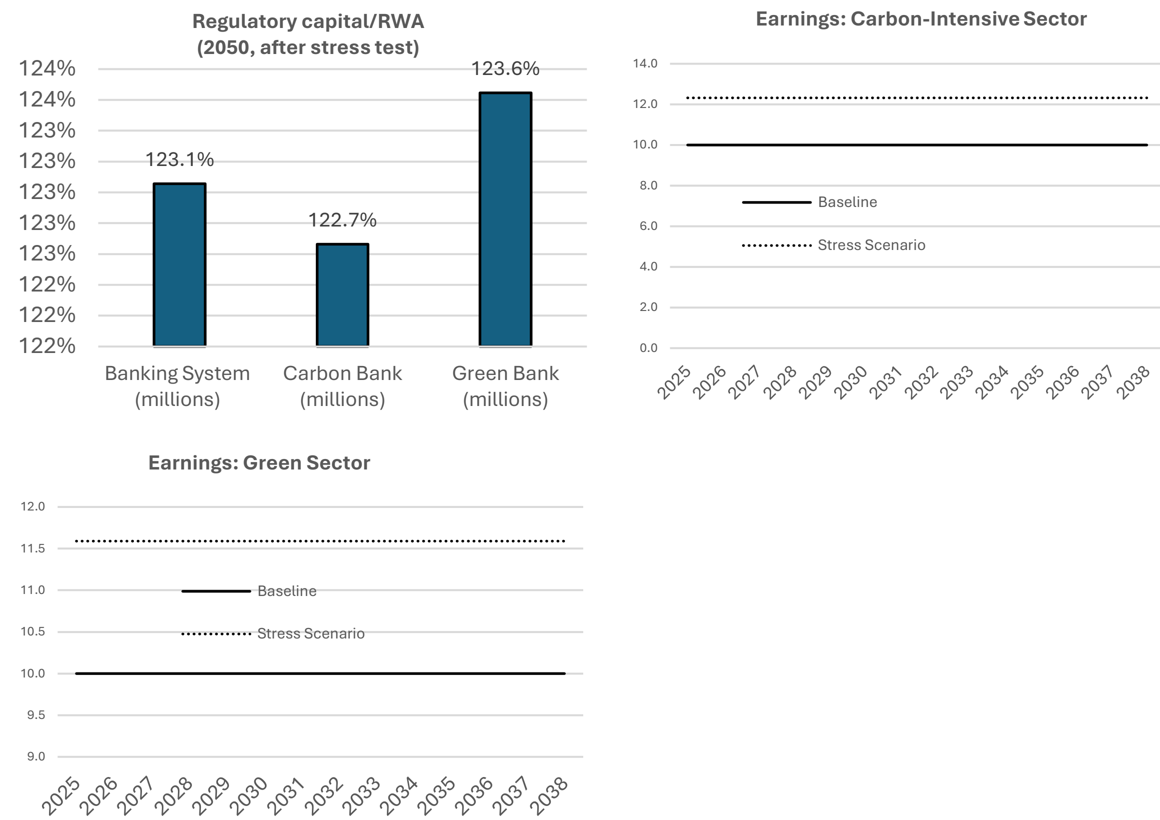
In Kyrgyzstan, the primary vulnerability arises from high sensitivity to external macroeconomic shocks, reflected in the sharp deterioration of financial indicators under stress conditions. Despite adequate initial capitalization, the system demonstrates relatively low resilience to negative shocks.

4.2.5 Transition Risk Scenarios

Sectoral shocks projected to 2027 (Minsky moment; earnings per share (EPS) transition: 12.32 for carbon-intensive sectors and 11.59 for clean sectors) produce the following outcomes. Kyrgyzstan's system CAR reaches 123.1% (carbon-intensive sectors: 122.7%; clean sectors: 123.6%), with an NPL ratio of 0.36% and net NPLs-to-capital of 2.48%. In Kazakhstan, the system CAR equals 14.7% (carbon-intensive sectors: 14.8%; clean sectors: 14.7%), with an NPL ratio of −399.5% and net NPLs-to-capital of −61.1%.

Figure 5 presents the effects of acute transition risks (e.g., carbon pricing and policy shifts) on Kyrgyzstan's banking sector under a Minsky moment scenario through 2027.

Figure 5: Kyrgyzstan: Transition Risk

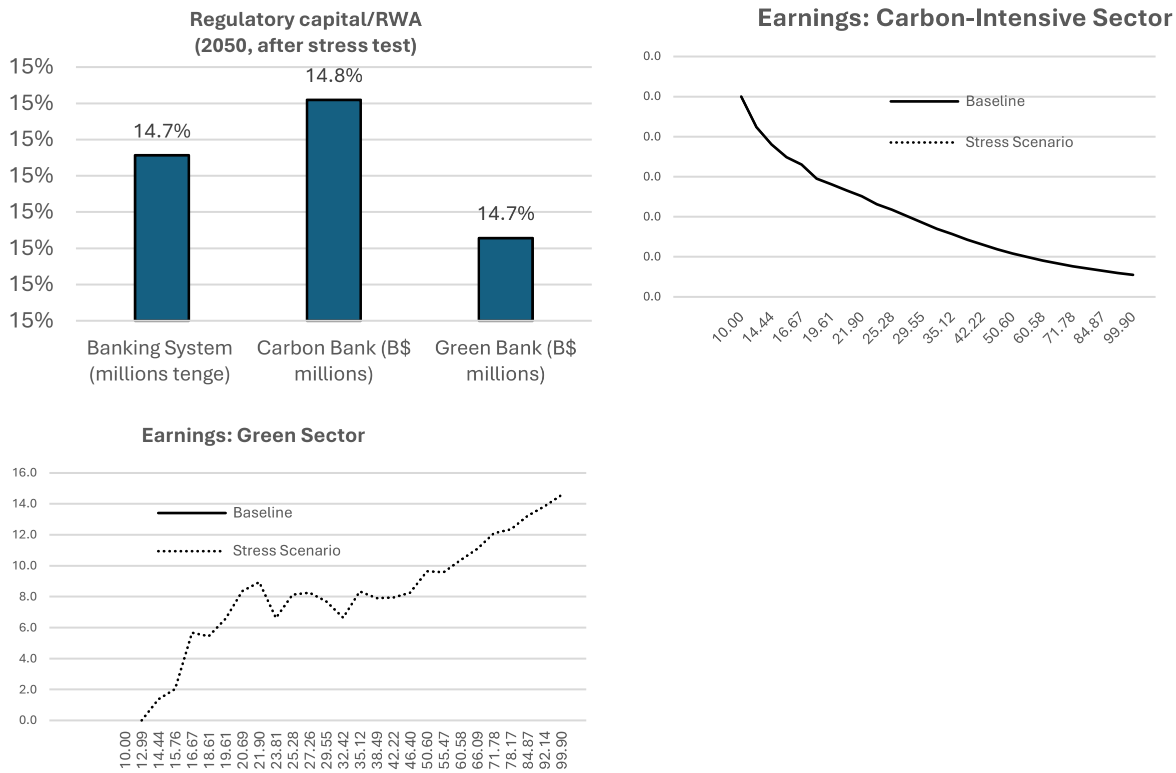


The figure uses bar charts to compare system-wide, carbon-intensive, and clean-sector indicators. The system CAR reaches 123.1% (baseline: 39.3%), with carbon-intensive sectors at 122.7% and clean sectors at 123.6%, reflecting differential EPS projections (12.32 for carbon-intensive sectors and 11.59 for clean sectors).

The NPL ratio stabilizes at 0.36%, while net NPLs-to-capital increases to 2.48% at the system level (2.08% for carbon-intensive sectors and 3.08% for clean sectors). A heatmap illustrates loan portfolio segmentation, showing a −3.99% system-wide change in NPLs associated with carbon tax equivalents. These results indicate modest sectoral disparities but overall resilience driven by the dominance of service-oriented exposures.

Figure 6 visualizes the effects of acute transition risks on Kazakhstan’s banking sector under a Minsky moment scenario through 2027.

Figure 6: Kazakhstan: Transition Risk



Bar charts present system-wide, carbon-intensive, and clean-sector financial soundness indicators. The system CAR rises to 14.7% (from −2.8%), with carbon-intensive sectors at 14.8% and clean sectors at 14.7%, reflecting EPS adjustments (12.32 for carbon-intensive sectors and 11.59 for clean sectors). The NPL ratio declines to −399.5% at the system level, while net NPLs-to-capital reaches −61.1% (−40.95% for carbon-intensive sectors and −91.57% for clean sectors). A heatmap of assumed loan exposures shows a −399.5% adjustment in NPLs due to carbon repricing, highlighting significant vulnerabilities in fossil-fuel-dependent sectors and the need for rapid economic diversification.

4.3 Critical Threshold Analysis

Research Task 4 identifies specific vulnerability thresholds and tipping points at which climate stresses could trigger systemic banking instability. Variations of ±20% around baseline assumptions under mild, moderate, and severe scenarios were used to evaluate uncertainty. For Kyrgyzstan, GDP effects (base range: −4.2% under mild conditions to −13.5% under severe conditions) varied from −3.04% to −17.73%. NPL changes (4.5%–13.5%) ranged from 3.26% to 17.73%, while carbon equivalents (5%–40%) ranged from 3.62% to 52.55%. For Kazakhstan, GDP impacts (−3.5% to −12.0%) ranged from −2.52% to −15.83%. NPL responses (2.52%–12.0%) ranged from 2.52% to 15.83%, and carbon adjustments (10%–50%) ranged from 7.21% to 65.94%. These variations increased deviations in financial soundness indicators by approximately 10–25%, supporting the model's robustness while identifying potential tail risks. ost-shock comparisons indicate pronounced declines in Kyrgyzstan under physical risks (−3.3% net NPLs-to-capital) and in Kazakhstan under transition risks (−61.1%).

4.4 Discussion

The results highlight differing vulnerabilities of the banking systems of Kyrgyzstan and Kazakhstan to macroeconomic and climate risks, consistent with the broader literature on financial stability in emerging markets. Kyrgyzstan's high reliance on remittances (25-30% of GDP) amplifies NPL increases in response to exchange-rate and migration shocks, consistent with patterns observed in other labor-exporting economies. Under the conventional stress scenario, the simulated CAR declines to −229.8%, reflecting historical volatility such as the 2008 crisis, when remittance flows fell sharply, implying recapitalization needs exceeding the 8% regulatory threshold.

Kazakhstan's resource-intensive economic structure (29% of industrial GDP) increases exposure to transition risks. Under physical stress scenarios, NPL ratios reach 28.3 %, consistent with IMF assessments of the vulnerability of oil-exporting economies to global policy shifts.

Comparative analysis shows that Kyrgyzstan is more exposed to physical risks (e.g., −5.1% securities losses) due to its service-oriented growth model, whereas Kazakhstan faces more acute transition risks (e.g., −26.6% securities devaluation). This pattern highlights the need for energy diversification in Kazakhstan, as suggested in regional policy studies. Sensitivity analysis confirms model robustness, as ±20 % parameter changes alter financial soundness indicators by 10-25% without changing the overall conclusions.

These results have important policy implications. Central banks should integrate climate scenarios into prudential frameworks in line with NGFS recommendations. Kyrgyzstan should prioritize remittance buffers and external shock stabilization mechanisms, while Kazakhstan should expand green finance initiatives, including those associated with the Astana International Financial Center (AIFC). Greater data granularity would also reduce methodological limitations, particularly those related to sectoral exposure assumptions and truncated historical datasets that may underestimate tail risks. Future research could incorporate dynamic stochastic general equilibrium models to simulate climate–financial interactions more accurately in Central Asian economies.

The modeling results also reveal a counterintuitive outcome of long-term climate impacts on banking stability. Both countries display a “climate paradox,” whereby long-term physical climate risks coincide with improvements in some banking system indicators. This effect may arise from structural adjustment processes in which climate pressures stimulate economic restructuring and more efficient resource allocation. Adaptation investments may increase credit demand and stimulate banking activity, while expectations of active government climate policy may improve long-term sector prospects.

This “climate paradox” should not be interpreted as a modeling error but as an emergent outcome of adaptive restructuring. Over time, sustained exposure to climate shocks may force sectoral transformation and the reallocation of capital, effectively removing inefficient balance-sheet components. Apparent improvements in CAR and profitability therefore reflect systemic adaptation rather than short-term recovery. This interpretation aligns with the concept of dynamic resilience, in which stability emerges through structural transformation rather than the preservation of pre-shock conditions.

Comparative assessment allows the banking systems to be ranked by resilience across different risk horizons. In the short term, Kyrgyzstan demonstrates stronger pre-shock conditions, followed by Kazakhstan. In the long term, Kyrgyzstan shows a recovery coefficient of 426.9%, exceeding Kazakhstan’s projected 19.1%.

The results also carry implications for regulatory policy. In Kazakhstan, priorities include banking sector recapitalization, the development of macroprudential tools for systemic risk management, and the establishment of dedicated mechanisms for monitoring climate-related financial risks. In Kyrgyzstan, policy priorities include strengthening capital buffers, developing early-warning systems for macroeconomic imbalances, and integrating climate scenarios into routine stress-testing exercises.

At the regional level, policy coordination should focus on harmonizing climate risk assessment methodologies, establishing mechanisms for sharing systemic risk information, and developing joint crisis response frameworks.

Taken together, the empirical evidence confirms that the stress-testing framework effectively identifies distinct vulnerability profiles in the two banking systems. Kyrgyzstan's exposure to remittance-driven external shocks contrasts with Kazakhstan's dependence on carbon-intensive sectors, underscoring the structural heterogeneity of climate-financial risk transmission in Central Asia.

5. Recommendations

This section addresses Research Task 5 by developing differentiated prudential measures, supervisory practices, and regulatory reforms tailored to each country's climate-financial risk profile. The discussion integrates empirical findings with the theoretical propositions outlined in the Introduction and interprets them through the framework of differentiated climate-financial transmission mechanisms. Please see Table 3 for a summary list.

Table 3: Synthesis of Research Tasks, Quantitative Results, and Policy Recommendations

Research Task	Key Quantitative Result (from model)	Policy Recommendation
Task 1. Structural vulnerability	Asymmetric exposure: remittance-dependence (KR) vs. oil-sector reliance (KZ)	Differentiated prudential frameworks reflecting external vs. transition risks
Task 2. Transmission mechanisms	Dual channels: FX–inflation–credit (KR); oil–fiscal–liquidity (KZ)	Country-specific early-warning indicators and FX-capital buffers
Task 3. Quantitative stress testing	CAR = −229.8% under RCP 8.5 (KR); NPL = 126.6% (KZ)	Remittance-linked liquidity buffers (KR); carbon-linked capital charges (KZ)
Task 4. Threshold detection	Fragility thresholds: NPL > 100%; CAR < 0%	Integrate tipping-point indicators into macroprudential supervision
Task 5. Policy framework	Scenario-based policy roadmap (2024–2030)	Adaptive regulation and green finance incentives

Notes: This table links empirical outcomes to the five research objectives for qualitative policy design. The roadmap operationalizes findings for regulatory and supervisory practice.

The evidence confirms that the mechanisms identified in the methodological framework - remittance flows in Kyrgyzstan and oil price dynamics in Kazakhstan - are empirically supported by the stress-testing results. The comparative framework therefore operationalizes the central research hypothesis by linking theoretical propositions with model-based outcomes. The results show that physical risks dominate in Kyrgyzstan, whereas transition risks are more pronounced in Kazakhstan.

The empirical findings reveal distinct vulnerability patterns that require differentiated policy responses reflecting country-specific transmission channels and institutional capacities. The stress-testing framework demonstrates that conventional prudential measures are insufficient under integrated climate-economic scenarios, indicating the need for adjustments to regulatory frameworks, supervisory practices, and market development strategies in both countries.

5.1 Kazakhstan: Managing Commodity Dependence and Transition Risks

The stress-test results indicate significant vulnerabilities in Kazakhstan's banking system stemming from foreign-exchange exposure and concentration in carbon-intensive sectors. Net FX position-to-capital ratios reaching 116.2% under severe scenarios substantially exceed prudential norms. Transition risk assessments further indicate that NPL ratios could fall to −399.5% in carbon-intensive sectors under disorderly transition scenarios. These findings point to the need for targeted regulatory interventions to reduce systemic risk.

Enhanced foreign-exchange risk management represents the most immediate priority. The National Bank of Kazakhstan should introduce mandatory limits requiring banks to maintain net open FX positions below 10% of Tier 1 capital, with additional buffers for institutions with significant exposure to the oil sector. Monthly reporting of currency-matched assets and liabilities should include automatic intervention triggers at an 8% threshold, requiring corrective measures. This approach addresses the mismatch between foreign-currency earnings and domestic-currency lending that heightens vulnerability to commodity price volatility (Klusak et al., 2021).

Sectoral concentration management is also essential given the economy's reliance on extractive industries. Regulatory authorities should limit individual bank exposure to oil and gas sectors to 25% of total loan portfolios by 2026, declining to 20% by 2030. At the same time, reduced risk weights of 75% - rather than the standard 100% - for loans supporting renewable energy and energy-efficiency investments would encourage portfolio diversification while maintaining credit availability for economic transformation.

Dynamic provisioning mechanisms can mitigate procyclical lending behavior associated with commodity cycles. Countercyclical provisioning rates could range from 2-4% during oil price booms and 0.5-1% during downturns, calibrated against deviations from a 24-month moving average. This approach would build financial buffers during favorable periods while preserving lending capacity during stress episodes, following precedents in other resource-dependent economies (Battiston et al., 2017).

5.2 Kyrgyzstan: Addressing Remittance Dependency and External Vulnerabilities

Kyrgyzstan's banking system shows high sensitivity to remittance-driven external shocks, with capital adequacy ratios declining to −229.8% in stress scenarios incorporating remittance volatility and exchange-rate pressures. The economy's dependence on migrant remittances creates transmission channels that standard prudential frameworks rarely address.

These findings confirm that institutional and structural characteristics shape the financial impact of climate shocks. In Kyrgyzstan, remittance inflows create a distinct macrofinancial vulnerability through the external sector. In contrast, Kazakhstan's exposure to global carbon markets and oil price volatility generates transition-related credit risks. The differing structures of these transmission channels reinforce the need for country-specific regulatory strategies rather than uniform policy responses.

Remittance-linked liquidity management should introduce additional liquid asset requirements of 2–5% of deposits when annual remittance inflows decline by more than 15%. Buffer calibration should reflect each institution's exposure to remittance-dependent clients, using foreign-currency deposit ratios as proxy indicators. This approach recognizes that remittance volatility produces liquidity pressures distinct from traditional funding shocks (Feyen et al., 2021).

Migration-sensitive credit assessment should require banks to stress-test retail loan portfolios assuming 25–30% declines in remittance flows, reflecting historical volatility during regional crises. Enhanced due diligence should apply when household income depends more than 50% on remittances, incorporating factors such as migration destination diversification and seasonal income variation.

Economic diversification incentives could further reduce systemic risk by providing preferential capital treatment for loans supporting domestic value-added sectors and South–South migration corridors. Capital relief for financing small and medium enterprises in manufacturing and services would encourage a gradual shift away from remittance-dependent household lending toward productive economic activities.

5.3 Climate Risk Integration Framework

Kazakhstan faces dual transition challenges arising from its reliance on carbon-intensive industries and growing water scarcity in southern regions. The interaction between decarbonization pressures and water constraints increases credit risks in the energy, agriculture, and metallurgy sectors. Key adaptation priorities include financing water-efficient technologies, developing a transition bond market, and conducting supervisory stress testing of stranded-asset exposures.

Kyrgyzstan's vulnerability stems from its dependence on remittance inflows and exposure to climate-induced disasters such as droughts and landslides in mountainous areas. These pressures intensify foreign-exchange and credit risks, requiring remittance-linked liquidity buffers and targeted insurance mechanisms. Strengthening adaptation lending and infrastructure resilience therefore represents the most effective pathway for risk mitigation.

Both countries must integrate climate risks into prudential frameworks, although implementation should reflect their distinct vulnerability profiles. Physical climate risks primarily affect Kyrgyzstan through water variability and extreme weather events, whereas Kazakhstan faces more pronounced transition risks linked to global decarbonization policies and the revaluation of fossil-fuel assets.

Mandatory climate stress testing should incorporate multiple warming pathways, including 2°C and 4°C scenarios by 2030, with sectoral priorities reflecting each country's economic structure. For Kazakhstan, analysis should focus on energy-sector transition risks and water stress in southern agricultural regions. Kyrgyzstan's stress testing should prioritize drought impacts on agriculture, flood risks in the Bishkek and Osh valleys, and landslide exposure in mountainous regions.

Geographic risk mapping enables spatial assessment of loan portfolio exposure to climate hazards. Kazakhstan requires systematic evaluation of exposure to water-stressed regions such as the Aral Sea basin and southern oblasts. Kyrgyzstan should map flood-prone urban areas and landslide-susceptible mountainous zones. Risk-weighted asset adjustments could incorporate geographic exposure concentrations to encourage diversification and adaptation investment.

Carbon-linked capital requirements should introduce additional capital charges based on sectoral carbon intensity: 2-5% for oil and gas exposures, 1-3% for heavy industry, and 0.5-1% for transport lending. A gradual three-year phase-in period would allow banks to adjust portfolios while quarterly reporting of carbon-intensity indicators supports supervisory monitoring of transition progress.

Integrating climate risks requires an evolution of supervisory practices beyond traditional microprudential approaches. The supervisory review and evaluation process should include climate risk assessments based on each bank's geographic and sectoral exposure profile, conducted annually with quarterly monitoring of key vulnerability indicators.

Early-warning systems should incorporate country-specific climate-economic triggers aligned with identified transmission channels. In Kazakhstan, enhanced monitoring should activate when Brent crude prices fall below $45 per barrel. In Kyrgyzstan, alerts should trigger when monthly remittance inflows decline by more than 20% year-on-year. Real-time monitoring of climate–finance indicators would enable faster supervisory responses to emerging risks.

Disclosure and transparency requirements, aligned with the Task Force on Climate-Related Financial Disclosure recommendations, should be implemented by 2026. Central banks should publish system-wide climate risk indicators to strengthen market discipline. Greater transparency can improve climate risk pricing while supporting the development of green finance markets (Task Force on Climate-related Financial Disclosures, 2023).

5.4 Regional Cooperation and Market Development

Regional coordination of climate-financial risk management is essential given shared environmental pressures and economic interconnections through trade and migration. Joint climate-finance databases would support cross-border risk assessment, while harmonized standards could reduce regulatory arbitrage and enhance regional financial stability.

Green finance market development requires differentiated approaches reflecting each country's economic structure and institutional capacity. These measures address the final research objective - developing prudential and policy instruments tailored to country-specific vulnerabilities. The findings also support the conceptual link between financial resilience and structural transformation, suggesting that climate policy can promote sustainable economic diversification when integrated into financial supervision. Kazakhstan can leverage the AIFC Green Finance Center for international green bond issuance and sustainable finance innovation, while Kyrgyzstan should prioritize domestic green lending standards and certification systems appropriate to a smaller market.

Implementation sequencing should follow a three-phase approach. The first phase (2024-2025) focuses on foundational measures, including legal frameworks and supervisory capacity building. The second phase (2025-2027) introduces climate stress testing and sectoral concentration limits. The final phase

(2027-2030) emphasizes dynamic risk-weighted asset frameworks and alignment with international regulatory standards.

Success measurement should include quantitative targets such as reducing sectoral concentration by 15–20% by 2027, improving system-wide climate risk indicators with Z-scores above 15 under stress scenarios, and expanding green finance to 5–10 % of total credit allocation by 2030. These benchmarks provide measurable indicators for evaluating policy effectiveness while aligning with broader sustainable development goals.

Overall, the discussion confirms the achievement of the five research tasks outlined in the Introduction: identifying structural vulnerabilities, specifying transmission mechanisms, conducting stress testing under physical and transition scenarios, determining systemic thresholds, and developing differentiated policy responses. The alignment between methodological design and empirical outcomes strengthens the study's contribution to the literature on climate-financial resilience in emerging economies.

The proposed policy framework addresses the vulnerabilities identified in the empirical analysis while building adaptive capacity to manage escalating climate pressures. Successful implementation will depend on sustained political commitment, institutional capacity development, and coordinated regional strategies that recognize the environmental and economic interdependence of Central Asian economies.

6. Conclusion

This study provides the first comprehensive assessment of climate-related financial risks in the banking systems of Kazakhstan and Kyrgyzstan and identifies fundamental differences in vulnerability patterns and adaptation requirements. Using integrated VAR modeling and climate-enhanced stress testing, the analysis shows that conventional financial stability frameworks require substantial modification to address the combined effects of physical climate impacts and the transition to a low-carbon economy.

Key Empirical Findings

The analysis identifies three central findings that challenge prevailing assumptions about financial stability in Central Asia. First, transmission mechanisms differ significantly between the two countries. Kyrgyzstan's banking sector is highly sensitive to remittance-driven external shocks, with the simulated

CAR declining to −229.8% under stress scenarios (a model-derived indicator of capital shortfall, not a directly observed ratio). Kazakhstan, in contrast, faces heightened vulnerability to commodity price volatility and stranded-asset risks, with model-derived NPL ratios reaching −399.5% in carbon-intensive sectors under disorderly transition assumptions (a diagnostic value reflecting projected loan losses relative to the capital base). These country-specific channels generate distinct systemic risk profiles that require differentiated policy responses.

Second, existing capital buffers appear insufficient under combined climate–economic stress conditions. Although both banking systems maintain regulatory capital ratios above Basel III minimum requirements under baseline conditions, the integration of physical and transition risks reveals critical vulnerabilities. Kyrgyzstan's relatively high baseline capitalization (39.3% CAR) offers limited protection against compound shocks, while Kazakhstan's resource-dependent economic structure intensifies transition risks through sectoral concentration.

Third, long-term climate adaptation produces paradoxical implications for financial stability. The results indicate that gradual physical climate risks may eventually strengthen banking resilience by encouraging economic diversification and improving risk management practices. However, abrupt transition shocks pose more immediate systemic threats. This outcome challenges linear risk projections and highlights the importance of carefully designed transition pathways.

Methodological Contributions and Limitations

The study advances climate-finance modeling through several methodological contributions. Integrating VAR forecasting with CPAT-based stress testing enables dynamic projections that extend beyond traditional static balance-sheet analysis. Identifying country-specific transmission channels also allows policy responses to be calibrated to structural characteristics of each economy. Furthermore, the decomposition of banking portfolios into carbon-intensive and clean sectors provides a practical approach for evaluating transition risks in data-constrained environments.

Nevertheless, several limitations affect the reliability of long-term projections. The assumption of parameter stability over a 25-year horizon may underestimate the effects of structural change as climate policies evolve and economic structures adjust. VAR models estimated using limited historical data (2005-2024) may not fully capture regime shifts or nonlinear climate-economic relationships. In addition, sectoral loan exposure estimates - derived from macroeconomic proxies due to data constraints - introduce uncertainty into transition risk calculations that may affect policy interpretation.

Projection uncertainty also increases over time. Forecasts extending to 2050 are subject to multiple sources of error, including uncertainty in climate scenarios, economic structural change, and evolving regulatory regimes. Although the study addresses some of these issues through sensitivity analysis (±20% parameter variations) and conservative interpretation of long-term outcomes, uncertainty regarding future climate-economic relationships remains significant.

Policy Implications and Strategic Priorities

The results highlight several policy priorities for addressing climate-related financial risks. In Kazakhstan, immediate improvements in foreign-exchange risk management and sectoral diversification are essential. These measures include limits on oil-sector lending exposure and stronger currency-matching requirements. The findings also support the gradual introduction of carbon-linked capital requirements to encourage portfolio rebalancing while avoiding abrupt transition shocks.

In Kyrgyzstan, policy priorities include remittance-linked prudential buffers and migration-sensitive credit risk assessment. Liquidity requirements tied to remittance volatility could reduce systemic vulnerability to external shocks. Kyrgyzstan's relatively low-carbon intensity also presents opportunities for developing green finance markets without significant transition-related disruption.

Regional cooperation is equally important given shared climate vulnerabilities and economic integration across Central Asia. Harmonized climate risk assessment methodologies, joint early-warning systems, and coordinated regulatory frameworks could strengthen systemic resilience while reducing regulatory arbitrage.

Research Agenda and Future Directions

The findings open several avenues for future research. Developing region-specific climate–economic models is an immediate priority, particularly those incorporating Central Asian climate dynamics, water resource constraints, and cross-border environmental interdependencies. Improved bank-level and sectoral data would also enable more precise quantification of climate-related financial risks.

Future modeling approaches could include dynamic stochastic general equilibrium frameworks incorporating climate variables to address parameter stability concerns. Agent-based models may also better capture behavioral responses to climate policies and financial stress. Additionally, machine learning techniques could improve identification of nonlinear climate–finance relationships and enhance forecasting of tail risks.

Operational research priorities include the development of real-time climate risk monitoring systems, standardized green finance taxonomies tailored to Central Asian conditions, and stress-testing frameworks capable of modeling tipping points and cascading systemic effects.

Concluding Assessment

The banking systems of Kazakhstan and Kyrgyzstan face material climate-related financial risks that require immediate policy attention and long-term strategic adaptation. Although current capital levels may absorb moderate short-term shocks, the combined effects of climate impacts and economic transition risks necessitate proactive prudential policies and strengthened supervisory frameworks.

The opportunity for gradual adaptation is narrowing. Delayed integration of climate risks increases the likelihood of disorderly economic transitions and financial instability. At the same time, well-designed climate–finance policies can support economic development by directing investment toward resilient infrastructure and sustainable diversification.

These findings highlight that climate risks represent structural challenges to existing financial stability frameworks rather than incremental extensions of traditional risk categories. The differentiated vulnerability patterns identified in this study require country-specific responses embedded within coordinated regional strategies supported by improved data systems and analytical capacity.

Climate resilience in Central Asian banking systems ultimately depends on broader economic transformation toward more diversified and sustainable development models. Financial sector policies can facilitate this transition while preserving systemic stability, but their effectiveness depends on integration with broader climate mitigation and adaptation strategies across the wider economy.

The central hypothesis of this study is therefore empirically confirmed. Kyrgyzstan’s banking system is primarily vulnerable to physical climate risks transmitted through remittance and external demand shocks, whereas Kazakhstan’s system is dominated by transition risks associated with carbon-intensive assets and global decarbonization dynamics. This dual outcome supports the proposed conceptual framework of asymmetric climate-financial transmission mechanisms in emerging Central Asian economies.

The results underscore both the urgency of climate–finance integration and the feasibility of maintaining financial stability during the transition to low-carbon economies. With appropriate policy design and implementation, the banking systems of Kazakhstan and Kyrgyzstan can support sustainable development rather than constrain the structural transformation required for climate resilience.

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