South African Reserve Bank

Working Paper Series

WP/25/11

Climate-related transition risks in Southern African banks: financial exposure and policy implications

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Authorised for publication by Konstantin Makrelov

14 August 2025

South African Reserve Bank

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Climate-related transition risks in Southern African banks: financial exposure and policy implications

Paola D'Orazio,* Torsten Schmidt† and Maximilian Dirks‡

Abstract

This paper investigates climate-related transition risks in the financial sectors of Botswana, Namibia, Mozambique and South Africa, focusing on exposure to carbon-intensive industries and the macrofinancial transmission of transition shocks. Drawing on sectoral loan allocation data, greenhouse gas emissions and transition risk metrics, the analysis applies the Climate Policy Relevant Sectors taxonomy, loan carbon intensity and a transition risk index to quantify financial sector vulnerabilities across the four economies. To assess the macrofinancial effects of transition risk shocks, a set of country-specific Bayesian vector autoregression models is estimated. The results reveal heterogeneous responses: while transition shocks lead to current account deterioration in Namibia and South Africa, trade volumes show resilience or expansion, particularly in Botswana. Credit supply and non-performing loans respond only modestly, with financial sector effects remaining limited and sensitive to identification strategies. The findings underscore the importance of integrating transition risk into financial supervisory frameworks. Enhancing climate-related prudential regulation – through improved risk disclosure, stress testing and capital requirements for high-carbon exposures – can strengthen financial system resilience and facilitate the reallocation of capital towards low-emission sectors. Aligning domestic regulatory practices with international climate finance standards will be essential to mitigate systemic risks and ensure stability during the transition to a low-carbon economy.

JEL classification

G21, Q54, E58, G28

Keywords

Climate-related transition risks, banking sector exposure, greenhouse gas emissions, loan carbon intensity, Southern Africa

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1. Introduction[1]

Climate-related transition risks emerge from the economic and financial adjustments required to shift towards a low-carbon economy (Carney 2015; Puyo et al. 2024). These risks are driven by evolving environmental policies, technological advances, market shifts and changing social preferences that place increasing pressure on carbon-intensive industries (Basel Committee on Banking Supervision (BCBS) 2021b). As governments and businesses accelerate decarbonisation efforts, established industries face increasing regulatory and financial constraints, particularly in emerging markets and developing economies, where structural dependencies on high-emission sectors are more pronounced (Stechemesser et al. 2024). At the same time, policies such as carbon pricing, emission caps and incentives for renewable energy adoption erode the profitability and long-term viability of industries dependent on fossil fuels, creating far-reaching economic and financial consequences (Network for Greening the Financial System (NGFS) 2017; BCBS 2021b).

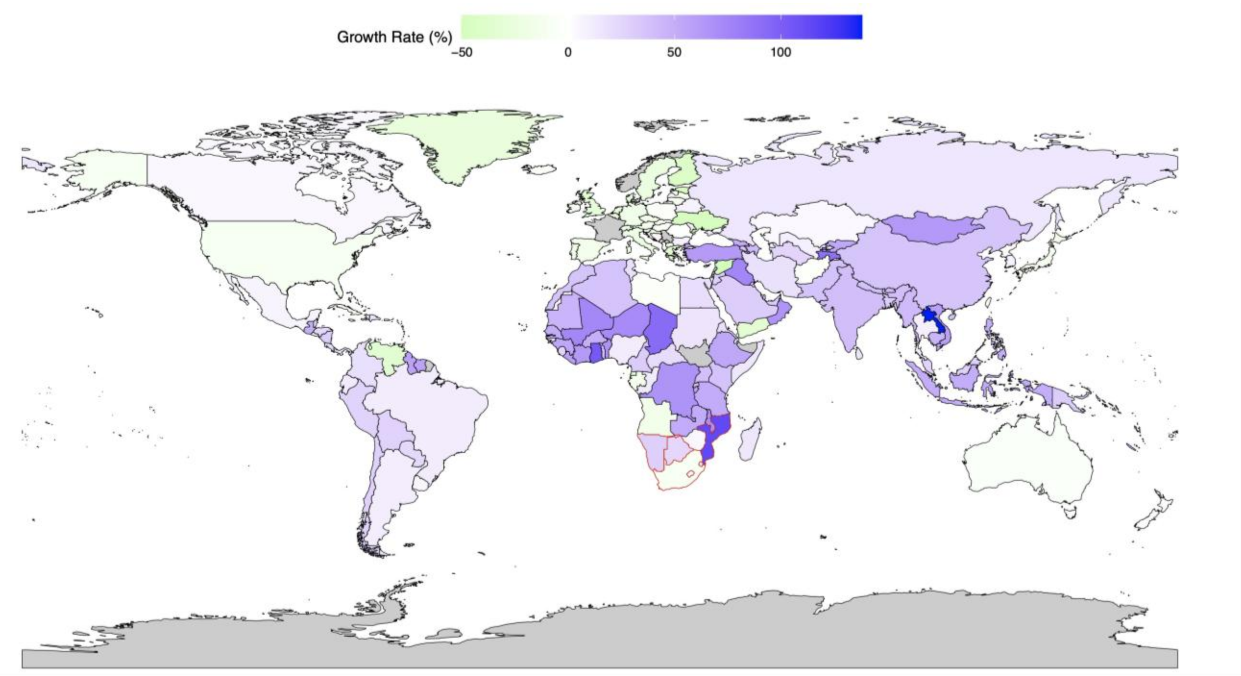
The financial sector plays a central role in this transition due to its exposure to industries undergoing decarbonisation and its function in allocating capital across the economy (Schnabel 2020; De Bandt et al. 2023). The devaluation of carbon-intensive assets poses a direct threat to financial stability (Caldecott et al. 2021). Credit risks for banks increase as borrowers in high-emission industries face higher costs of compliance and diminishing profitability (BCBS 2021b). Carbon taxation, emissions trading schemes and new environmental standards contribute to this financial distress, affecting the creditworthiness of firms operating in sectors with high transition exposure (Semieniuk et al. 2021). Market repricing mechanisms further exacerbate risks as investors incorporate environmental, social and governance (ESG) criteria into their portfolio decisions, leading to capital shifts away from high-carbon industries. The resulting decline in asset valuations, coupled with liquidity shortages in carbon-intensive sectors, heightens systemic vulnerabilities within financial markets (Bolton et al. 2020). Additionally, the uncertainty surrounding the trajectory of the low-carbon

[1] The authors gratefully acknowledge Prof. Stefano Carattini, the participants of the Workshop of the Climate Change and Central Banking Research Programme hosted by the South African Reserve Bank (January 2024), the participants of the Southern African Development Community (SADC) Conference (February 2024), and an anonymous reviewer for their insightful and constructive feedback. Their comments have substantially improved the clarity and quality of this paper. All remaining errors are the sole responsibility of the authors.

transition complicates the risk assessment for financial institutions, emphasising the need for more robust climate-related financial disclosures, improved stress-testing methodologies and proactive regulatory measures to mitigate instability (Financial Stability Board 2020; BCBS 2021a; D'Orazio 2021; D'Orazio and Thole 2022; NGFS 2024).

Southern African economies face elevated transition risks due to their structural dependence on carbon-intensive sectors such as mining, energy generation and heavy manufacturing (Baker, Newell and Phillips 2014; Power et al. 2016). The region's continued reliance on coal for electricity production and industrial activity exacerbates its vulnerability to global decarbonisation dynamics and evolving domestic policy landscapes. Figure 1 presents the growth rates of total greenhouse gas (GHG) emissions between 2010 and 2022, illustrating the diverse transition trajectories across countries. South Africa shows a moderate decline in emissions, primarily attributed to policy-driven decarbonisation initiatives. In contrast, Botswana, Namibia and Mozambique continue to register emissions growth, reflecting the expansion of fossil-fuel-based energy systems and extractive industries. Notably, Mozambique has experienced a significant rise in emissions, which aligns with the rapid scaling up of coal mining and natural gas production, as documented by the International Energy Agency (IEA 2024a, b, c). These developments underscore Mozambique's increasing structural lock-in to carbon-intensive economic pathways.

Figure 1: Growth rate of total GHG emissions (2010–2022)

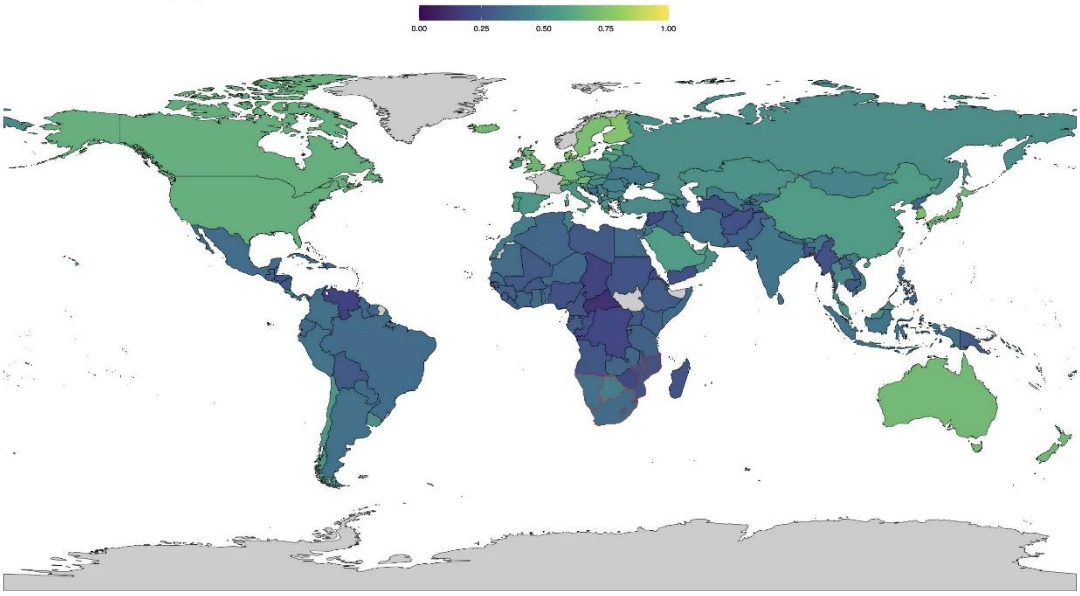


Note: The map shows the percentage change in GHG emissions across countries. Positive growth rates are shown in shades of purple, while negative growth rates are displayed in shades of green. Countries analysed in this study – Botswana, Namibia, Mozambique and South Africa – are highlighted in red.

Source: Authors' elaboration on Crippa et al. (2023) data

Variations in exposure to transition risks are amplified by differences in adaptive and institutional capacity, as reflected in the ND-GAIN Readiness Index. Figure 2 illustrates the relative readiness of Southern African economies to manage climate-related financial risks. South Africa and Botswana demonstrate comparatively higher levels of institutional strength, economic diversification and governance effectiveness, positioning them more favourably to anticipate and absorb transition shocks. Conversely, Namibia and Mozambique exhibit substantially lower readiness scores, pointing to weaker frameworks for climate risk management and policy implementation.

Figure 2: Global distribution of the ND-GAIN Readiness Index (2022)



Note: The index measures a country's ability to adapt to climate change, with values ranging from 0 (least ready) to 1 (most ready). South Africa shows higher readiness compared to its regional peers Botswana, Namibia and Mozambique.

Source: Authors' elaboration on ND-GAIN data

As Southern African economies become increasingly integrated into global trade and investment networks, transition risks extend beyond domestic financial institutions to affect trade competitiveness and capital inflows. The acceleration of net-zero targets in major economies and the introduction of carbon border adjustment mechanisms pose significant risks to export-oriented sectors (Magacho, Espagne and Godin 2024; Eicke et al. 2021). Foreign direct investment flows may shift towards countries with stronger climate policies, leaving economies with weak regulatory adaptation at a competitive disadvantage (Gu and Hale 2023). Socio-economic vulnerabilities further complicate the transition process, as carbon-intensive industries remain major employers in the region. If not carefully managed, the decarbonisation process may exacerbate inequality, drive up unemployment and trigger social unrest, thus underscoring the urgent need for a just and inclusive transition (Swilling, Musango and Wakeford 2016).

Despite increasing global attention to climate-related financial risks, there is little empirical research quantifying the exposure of financial institutions to transition risks in emerging markets (Daumas 2023; De Bandt et al. 2023). Most existing studies focus on financial systems in advanced economies such as the European Union (EU), where diversified capital markets, strong regulatory frameworks and economic structures differ significantly from those in resource-dependent emerging markets and developing economies (Battiston et al. 2017; Weyzig et al. 2014). Banking systems in Southern Africa remain highly concentrated in carbon-intensive sectors, making financial institutions in the region particularly vulnerable to the economic effects of decarbonisation (IEA 2019). The absence of granular and country-specific analyses of financial sector exposure to transition risks in this region represents a significant knowledge gap, limiting the capacity of policymakers and regulators to design effective mitigation strategies.

This study addresses this critical gap by systematically evaluating the exposure of banking systems in Botswana, Namibia, Mozambique and South Africa to climate-related transition risks. The paper contributes a novel index of transition risk exposure tailored to the structural characteristics of Southern African economies. Using sectoral loan data, GHG emissions and a transition risk index (TRI), we quantify financial institutions' vulnerabilities to high-emission sectors. We also assess the macrofinancial consequences of these risks using a Bayesian vector autoregression (BVAR) model, examining their dynamic impact on credit-to-gross domestic product (GDP), non-performing loan (NPL) ratios, trade volumes and the current account balance. These indicators capture both financial sector resilience and external vulnerability in economies structurally exposed to transition shocks. By bridging the gap between micro-level exposure and macroeconomic impacts, this analysis contributes to the design of effective, regionally tailored financial risk management frameworks.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature on climate-related financial risks and transition exposures. Section 3.1 outlines the theoretical framework, detailing the conceptual channels through which transition risks propagate from sectoral financial exposure to macroeconomic instability. Section 3 describes the data sources and methodological approach, including the construction of the loan carbon intensity (LCI) and the TRI, as well as the empirical design. Section 4 presents the results of the exposure assessment and the BVAR analysis of macrofinancial impacts. Finally, section 5 concludes with key policy recommendations and identifies priorities for future research.

2. Literature review

The study of climate-related financial risks has gained prominence in recent years, with increasing attention on their potential to destabilise financial systems. These risks are broadly categorised into physical and transition risks (Carney 2015). Physical risks arise from extreme weather events, leading to economic losses, asset devaluation and disruptions in financial markets (Botzen, Deschenes and Sanders 2019; Battiston et al. 2017; Caldecott et al. 2021). Transition risks emerge from regulatory changes, technological advances and evolving market expectations, which influence asset valuations and increase financial instability (Breitenstein, Nguyen and Walther 2021).

Financial institutions are exposed to climate-related risks through both direct and indirect channels. Direct exposures include loan defaults and asset devaluations linked to climate-vulnerable firms, while indirect exposures arise from macroeconomic downturns, supply chain disruptions and declining collateral values (Semieniuk et al. 2021). Assessing these risks presents methodological challenges, as financial institutions often lack comprehensive geospatial data for physical risks and standardised frameworks for measuring transition risks (BCBS 2021a; Ranger, Mahul and Monasterolo 2022; D'Orazio 2023b). Transition risk assessments typically rely on mapping risk drivers to counterparty and portfolio exposures, which form the basis for both microprudential and macroprudential policy responses (D'Orazio 2023a).

Several methodological approaches have been developed to quantify the financial impact of climate-related transition risks. Early studies by Weyzig et al. (2014) and the Bank of England's Prudential Authority Regulation (2015) provided some of the first estimates of transition risk exposure in the European financial sector. Weyzig et al. estimated that EU pension funds, banks and insurance companies faced transition risk exposures of about 5%, 1.4% and 4% of total assets, respectively. The Bank of England's Prudential Authority Regulation examined the United Kingdom's insurance sector, highlighting the vulnerability of life insurers to long-term asset repricing under alternative climate policy scenarios.

A key methodological advancement was the introduction of the Climate Policy Relevant Sectors (CPRS) taxonomy by Battiston et al. (2017), which classifies economic activities based on their exposure to climate policy risks. The CPRS framework has since been widely applied in financial risk assessments, including climate stress testing (Batten, Sowerbutts and Tanaka 2020; Monasterolo 2020), value-at-risk estimation (Dietz et al. 2016) and scenario analysis (Schulten et al. 2021). Empirical applications span several banking systems, including Austria (Battiston et al. 2020), Australia (Bellrose, Norman and Royters 2021), Italy (Faiella and Lavecchia 2020), Mexico (Roncoroni et al. 2021) and Hungary (Ritter 2022), with estimated transition risk exposures ranging from 0.3% to 61% of total loan portfolios.

Recent empirical work has expanded the application of CPRS and LCI measures to the German banking sector. D'Orazio, Hertel and Kasbrink (2024) provide the first systematic assessment of German banks' exposure to climate-related transition risks, employing three complementary methods: CPRS, LCI and carbon-critical sectors (CCrS). Their findings reveal that large private banks are particularly exposed, with estimated transition risk shares ranging from 19.4% (CCrS) to 32.6% (LCI) of total loan volumes. Their study identifies sectoral concentrations of risk in energy, transportation and manufacturing, and underscores the need for enhanced prudential oversight and disclosure practices. These insights reinforce the relevance of CPRS-based approaches and demonstrate their adaptability to different financial system structures.

Despite the growing body of research on climate-related financial risks, most empirical studies focus on advanced economies, leaving significant gaps in the literature on emerging markets. Research on African banks remains limited, despite the region's economic dependence on carbon-intensive industries and the associated risks to financial stability (Daumas 2023). Existing literature primarily examines the macroeconomic implications of climate policies but does not provide detailed assessments of financial sector vulnerabilities at the bank level.

The lack of climate-related financial data further complicates risk assessment in African banking systems. This gap is particularly concerning given the structural exposure of many African economies to fossil fuel extraction, mining and other emissions-intensive industries. Compounding the issue is the limited availability of climate-related financial data and weak regulatory mandates for disclosure. Unlike European and North American financial institutions, which are increasingly subject to climate-related financial disclosure requirements, African banks operate in regulatory environments where climate risk reporting remains underdeveloped. As a result, empirical studies quantifying transition risks at the bank level are scarce, limiting the ability of policymakers to design risk mitigation frameworks.

3. Conceptual and methodological framework

3.1 Theoretical framework

Building on the insights from recent literature on climate-related financial risks as discussed in section 2, we outline the conceptual framework guiding our analysis. While prior studies have categorised transition risks and proposed sectoral taxonomies, we apply these insights to construct a model linking financial exposure, credit allocation and macroeconomic performance in the context of Southern Africa's carbon-intensive economies.

At the core of the framework is the hypothesis that financial systems with significant credit exposure to high-emission sectors are more vulnerable to transition shocks. Financial institutions concentrated in sectors such as fossil fuels, utilities, energy-intensive manufacturing and transport are likely to face increasing default risks and asset revaluation pressures as climate policies are tightened (Caldecott et al. 2021; Semieniuk et al. 2021). These risks are exacerbated by the possibility of stranded assets, liquidity disruptions and sudden shifts in investor sentiment resulting from the repricing of environmental liabilities and ESG integration (Bolton et al. 2020; D'Orazio 2021).

Moreover, the macroeconomic feedback effects of climate-related transition risks are particularly pronounced in countries with high external dependence. For economies heavily reliant on emissions-intensive exports or fossil fuel investments, the adoption of carbon border adjustment mechanisms and evolving climate regulations in advanced economies can weaken trade balances, reduce capital inflows and erode the competitiveness of key sectors (Eicke et al. 2021). These channels introduce systemic vulnerabilities that go beyond firm-level credit risk and affect national accounts, external stability and long-term growth prospects.

To operationalise this framework, the analysis employs three metrics that quantify financial exposure to transition risks. The CPRS taxonomy developed by Battiston et al. (2017) is used to classify economic sectors by their exposure to climate policies. The LCI metric measures the carbon footprint of bank lending by mapping GHG emissions to sectoral loan volumes (Faiella and Lavecchia 2020; D'Orazio, Hertel and Kasbrink 2024). Building on these, the TRI combines emissions and credit allocation data to produce a composite indicator of systemic financial vulnerability. Together, these tools provide a robust framework for evaluating the exposure of financial systems to transition risks at both micro and macro levels.

To examine the dynamic macrofinancial consequences of transition shocks, the study employs a BVAR framework. This approach is appropriate for small samples and allows for the estimation of impulse response functions under sign restrictions. Specifically, it tests whether an exogenous increase in the TRI leads to adverse effects on key financial stability and macroeconomic indicators, such as the current account balance, credit supply and NPL ratios (Caldara et al. 2016; Azqueta-Gavaldón et al. 2023). The empirical design reflects the theoretical expectation that structural alignment between financial portfolios and high-emission sectors increases systemic fragility during a disorderly climate transition.

3.2 Data and variable description

This study focuses on Botswana, Namibia, Mozambique and South Africa, four Southern African countries whose economies are heavily reliant on carbon-intensive sectors such as coal mining, agriculture and heavy manufacturing. This structural dependence amplifies their vulnerability to climate-related transition risks.

The study covers the period from 2010 to 2022 because of the availability of sectoral loan data essential for assessing financial sector exposure to high-emission industries.[2] This period also coincides with a surge in global climate policy initiatives and energy transition efforts, providing a timely context for examining climate-related transition risks. Focusing on these years allows the study to capture critical trends in loan distribution, GHG emissions and financial vulnerabilities across the region.

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[2] While the timeframe ensures consistent data coverage across most countries, sectoral loan data for Namibia is only available through 2021. These gaps have been carefully accounted for to preserve the robustness and accuracy of the analysis.

The empirical analysis is based on a harmonised dataset that integrates sectoral loan data with sector-specific GHG emissions to evaluate the financial sector's exposure to both credit and climate-related transition risks. Sectoral loan data capture the distribution of credit across economic sectors within each national financial system. For Botswana and Namibia, these data were obtained from central bank annual reports; for Mozambique, from official loan statistics; and for South Africa, from financial statements and annual reports of major commercial banks.[3]

GHG emissions data comprise carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases, aggregated using Global Warming Potential (GWP-100) values from the IPCC AR5. Emissions are expressed in metric tons of CO_2 equivalent (CO_2eq) per year and were sourced from Our World in Data (Crippa et al. 2023). This provides a consistent and comprehensive measure of the carbon intensity associated with sectoral economic activity. The integration of financial and emissions data enables the identification of transition risks associated with credit exposure to high-emission sectors in carbon-intensive economies.

Macroeconomic indicators were drawn from the World Bank's World Development Indicators (WDI). Trade openness is measured as the ratio of total trade (exports plus imports) to GDP, while the current account balance (as a percentage of GDP) captures net flows from trade in goods and services, income and current transfers.

To assess financial stability, the analysis incorporates two key indicators: the NPL ratio and the credit-to-GDP ratio. The NPL ratio measures the share of NPLs in total gross loans and serves as a proxy for banking sector credit risk. The credit-to-GDP ratio reflects the extent of private sector credit relative to GDP, serving as an indicator of financial depth and leverage.

An overview of all variables, definitions, units of measurement, sources and country coverage is presented in Table 1.

3 Owing to the absence of standardised reporting formats, the dataset was compiled through a meticulous manual extraction process, addressing inconsistencies in terminology, structure and reporting practices across institutions and time (see Annexure A.1 and A.2).

Table 1: Overview of variables and data sources

Variable	Definition	Source/coverage
Sectoral loan volume	Credit allocated to each economic sector	Central banks, commercial bank reports (BWA, NAM*, MOZ, ZAF)
GHG emissions (CO_2eq)	Sectoral emissions including CO_2, CH_4, N_2O and fluorinated gases, aggregated using GWP-100 AR5	Crippa et al. (2023), Our World in Data (BWA, NAM, MOZ, ZAF)
NPL ratio	Share of NPLs in total gross loans, used to assess credit risk in the banking sector	World Bank, International Monetary Fund, national data sources (BWA, NAM, MOZ, ZAF)
Credit-to-GDP ratio	Domestic credit to the private sector as a percentage of GDP, indicating financial depth and leverage	World Bank WDI (BWA, NAM, MOZ, ZAF)
Trade openness	Sum of exports and imports as a percentage of GDP, reflecting trade integration	World Bank WDI (BWA, NAM, MOZ, ZAF)
Current account balance	Net flows from trade, services, income and current transfers as a percentage of GDP	World Bank WDI (BWA, NAM, MOZ, ZAF)

* Sectoral loan data for Namibia available through 2021 only.

3.3 Transition risk metrics

This section introduces the analytical framework used to evaluate the financial sector's exposure to climate-related transition risks. The analysis builds on three interrelated components. First, the CPRS classification is used to identify economic sectors most exposed to climate mitigation policies. Second, the LCI metric quantifies the carbon intensity of credit allocation across sectors, providing a measure of the environmental footprint embedded in financial portfolios. Third, the study develops a composite TRI to capture the aggregate exposure of national financial systems to transition risks, based on the interaction between sectoral loan volumes and GHG emissions. Together, these components offer a comprehensive and policy-relevant assessment of transition risk exposure in the region.

3.3.1 Climate Policy Relevant Sectors

The CPRS approach identifies and categorises sectors based on their relevance and exposure to climate policies (Battiston et al. 2017), emphasising areas of the economy directly affected by efforts to mitigate climate change. This categorisation is vital for understanding which sectors may face increased costs, regulatory pressures or shifts in demand due to such policies.

The CPRS methodology evaluates the financial and economic risks arising from climate policies. It identifies sectors directly or indirectly exposed to transition risks stemming from regulatory changes, market dynamics and technological advances to reduce GHG emissions. Under this framework, the most vulnerable sectors include *fossil fuels*, *utilities*, *energy-intensive industries*, *transport* and *housing/real estate*. These sectors are characterised by their dependence on carbon-intensive processes, exposure to stranded asset risks or significant contributions to GHG emissions:

- **Fossil fuels**: Activities related to oil, coal and gas production.
- **Utilities**: Particularly fossil-fuel-based electricity generation; facing risks from emissions regulations and the transition to renewable energy.
- **Energy-intensive industries**: Including steel, cement and chemicals; exposed to carbon pricing and rising energy costs.
- **Transport**: Sectors such as automotive, shipping and aviation; significantly affected by fuel efficiency standards and electrification policies.
- **Housing/real estate**: Influenced by energy efficiency requirements and sustainable building practices.

While *agriculture* has not traditionally been classified as a high-risk sector under CPRS, there are compelling reasons to include it. Agriculture contributes significantly to global GHG emissions, primarily through methane from livestock and nitrous oxide from fertilisers. It is increasingly subject to regulatory and market pressures targeting these emissions. Agriculture also relies on energy-intensive inputs (e.g. fertilisers) and is linked to high-risk sectors like transport for food distribution. Shifting consumer demand towards sustainable and plant-based food systems increases agriculture's exposure to transition risks. Furthermore, the physical risks of climate change, such as droughts and floods, can trigger regulatory responses that indirectly amplify transition risks for the sector. Including agriculture within the CPRS framework enhances the understanding of systemic risks associated with the climate transition.

Our CPRS taxonomy also incorporates the *trade* sector as a high-risk category due to its indirect but significant exposure to transition risks, particularly from carbon border adjustment mechanisms. For countries like Namibia and Botswana, which depend heavily on exporting carbon-intensive goods such as raw minerals and metals, these mechanisms could raise trade costs and reduce the competitiveness of these products in global markets (Eicke et al. 2021; Magacho, Espagne and Godin 2024). Additionally, the shift in global demand towards low-carbon goods and sustainable supply chains increases the vulnerability of trade-dependent economies. Recognising trade as a critical sector is thus essential for comprehensive climate transition risk assessments.

Annexure A.2 provides a detailed account of how economic sectors were mapped to the CPRS classification for each country using the proposed methodology.

3.3.2 Loan carbon intensity

LCI provides a robust framework for quantifying the carbon intensity of loans and identifying sectors that are critical contributors to carbon emissions (Faiella and Lavecchia 2020; D'Orazio, Hertel and Kasbrink 2024). Understanding the carbon intensity of loans is important for assessing how financial institutions contribute to climate change and managing the risks associated with transitioning to a low-carbon economy. The LCI thus offers a critical tool for aligning banking portfolios with climate goals such as those in the Paris Agreement.

The LCI is computed by mapping the GHG emissions of each economic sector *s* at time *t*, denoted as $GHG_{s,t}$, to the distribution of loans allocated to that sector at time *t*, represented as $LV_{s,t}$. This is expressed mathematically as:

$$LCI_{s,t} = \frac{GHG_{s,t}}{LV_{s,t}} \quad (1)$$

where $LCI_{s,t}$ quantifies the carbon intensity of loans by linking the environmental impact of economic sectors to their financial exposure through loan allocation. GHG emissions ($GHG_{s,t}$) are derived from Crippa et al. (2023). Loan volumes ($LV_{s,t}$) are obtained from financial institution records and often categorised by economic activity in line with standard industry classification codes.[4]

[4] See Annexure A.1 for further details.

The LCI ratio highlights the proportion of GHG emissions per unit of loan volume, helping to identify sectors where financial exposure is disproportionately linked to carbon-intensive activities. This insight is crucial for risk assessment and sustainable finance strategy development. Moreover, financial institutions can use the LCI to identify high-risk sectors in their portfolios, prioritise engagement with clients to reduce emissions and reallocate capital towards lower-carbon sectors. Regulators and policymakers can also use LCI metrics to guide the implementation of green finance policies.

3.3.3 Transition risk index

To quantify the financial exposure of each country to transition risks associated with the global shift towards a low-carbon economy, we develop a novel metric, the *transition risk index*. The methodological steps for constructing the index are detailed below. This approach directly weights sectoral emissions by the proportion of total loans allocated to that sector. The sectoral contribution to transition risk for each sector i at time t is computed as:

$$C_{i,t} = \left(\frac{L_{i,t}}{\sum_i L_{i,t}}\right) \times E_{i,t} \tag{2}$$

where:

- $L_{i,t}$ represents the loan allocation to sector i at time t
- $E_{i,t}$ represents the total GHG emissions of sector i at time t
- The fraction $\frac{L_{i,t}}{\sum_i L_{i,t}}$ captures the share of total loans allocated to sector i.

The overall TRI is obtained by summing the sectoral contributions:

$$\mathrm{TRI}_t = \sum_i C_{i,t} \tag{3}$$

This approach ensures that sectors with high financial exposure and high emissions contribute proportionally to the index.

3.4 Empirical estimation strategy

3.4.1 BVAR model

Given the limited number of annual time-series observations (2010–2022), we estimate BVAR models with two endogenous variables each, applying the Minnesota prior. The estimation process follows a two-step approach: first, we estimate the hyperparameters for the prior distributions; second, we estimate the model's coefficients conditional on these priors. All models include two lags and are based on 10 000 Monte Carlo replications.

The *transition risk index* serves as the core explanatory variable across all four model specifications. Each model also includes one of the following indicators: *current account balance*, *trade openness*, *credit-to-GDP ratio* or *NPL ratio*.

These supplementary variables capture key dimensions of financial stability, particularly through the lens of the balance of payments and the banking sector. The impact of transition risk shocks on external accounts and trade performance is closely linked to the carbon intensity of domestic production. Specifically, the effects on the current account are primarily driven by patterns of international investment. When exports are dominated by carbon-intensive goods, transition shocks tend to negatively affect trade openness. Conversely, economies with lower carbon intensity, or those exporting raw materials critical for the climate transition, may see improvements in trade openness.

Similarly, the effects of transition risks on credit volumes and NPLs depend on the carbon intensity of production. In economies with high carbon intensity, such shocks are more likely to reduce credit growth and increase the prevalence of NPLs.

3.4.2 Identification and robustness

Identifying shocks to transition risk is empirically challenging, as these risks are intertwined with real economic dynamics. To isolate a structural transition risk shock, we follow the identification strategy proposed by Caldara et al. (2016) and applied by Azqueta-Gavaldón et al. (2023). Specifically, we use the penalty function approach developed by Uhlig (2005), imposing a single sign restriction: the structural transition risk shock must have a positive impact on the TRI for at least one year after the shock. Since the goal is to isolate the dynamic response to a transition risk shock, other shocks are not explicitly identified within the BVAR framework. The transition risk shock is identified as the shock that maximises the response of the TRI over this time horizon.

As a robustness check, we estimate a BVAR model with two lags, employing Normal-Wishart priors for the parameter distributions. Structural shocks are identified using a Cholesky decomposition.

4. Results

4.1 Exposures analysis

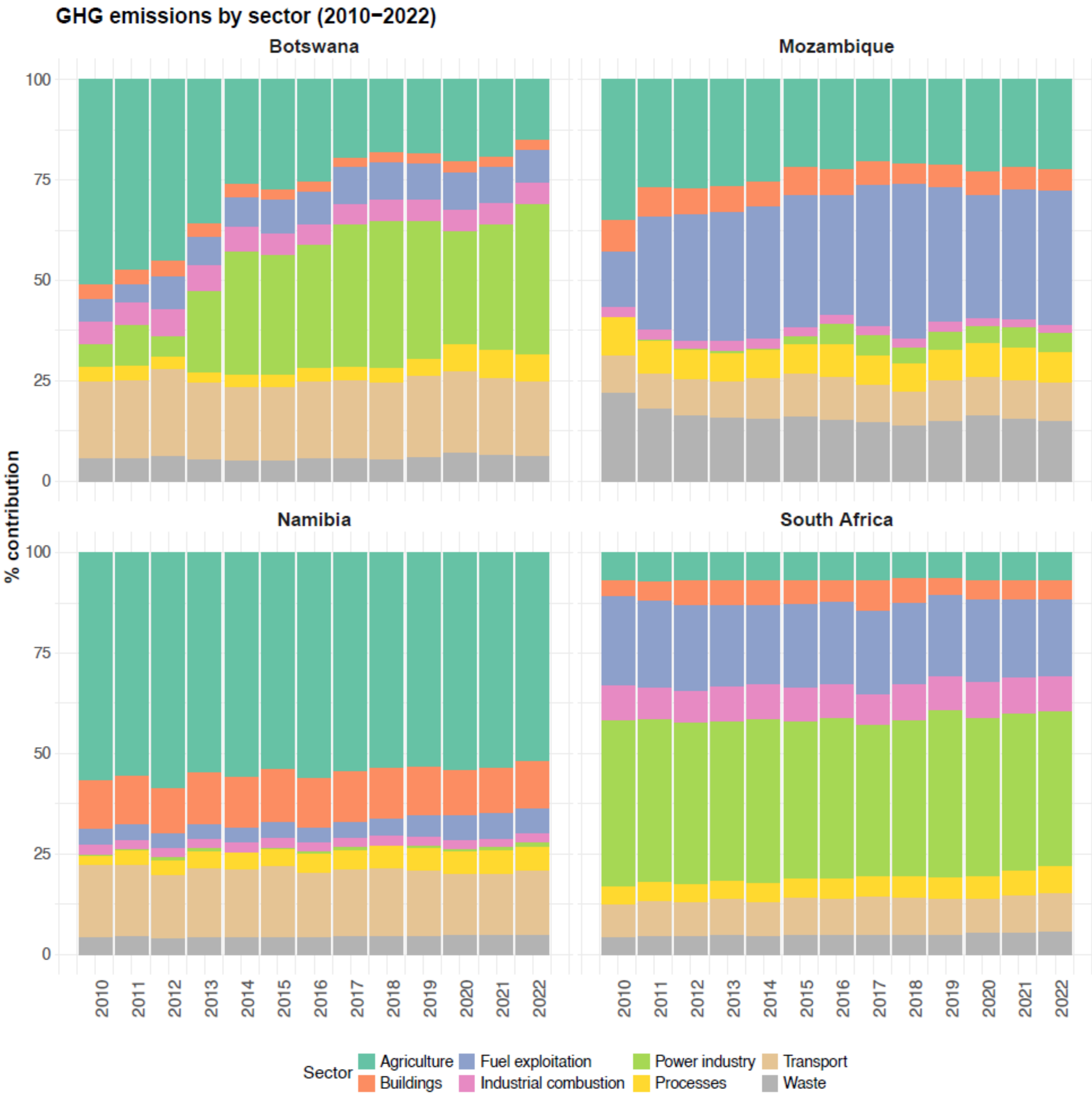
4.1.1 Sectoral GHG emissions

The dynamics of GHG emissions in Botswana, Namibia, Mozambique and South Africa reflect varying levels of industrialisation, energy dependency and economic structures. While these countries differ significantly in their emissions profiles, understanding the climate-related transition risks they face is crucial for ensuring long-term economic stability, energy security and sustainable development (IEA 2019).

South Africa remains the largest GHG emitter in the region, largely due to its reliance on coal for electricity generation and industrial activities. However, when considering total GHG emissions, the profiles of Mozambique, Botswana and Namibia gain greater relevance. Mozambique's growing liquefied natural gas sector contributes to increasing methane emissions, which have a significant short-term warming potential. Similarly, Botswana and Namibia exhibit substantial methane and nitrous oxide emissions associated with livestock farming, a key sector in their economies. These sources introduce additional transition risks beyond those associated with CO_2 alone (IEA 2019).

Figure 3 shows sectoral contributions to GHG emissions in the focus countries. In Botswana, the agricultural sector dominates, with relatively stable contributions from other sectors, while emissions from industrial combustion and industrial processes exhibit noticeable variability over the years. Namibia's GHG emissions profile is characterised by consistent contributions from the transport and power industry sectors, with smaller fluctuations in other sectors, reflecting the stability of its emissions distribution despite potential policy or economic influences. In Mozambique, agriculture plays a pronounced role in the emissions profile, coupled with notable changes in the relative contributions of industrial combustion and processes, suggesting shifts potentially driven by technological or economic developments. South Africa's emissions profile is dominated by energy-intensive sectors such as the power industry and transport, with smaller but steady contributions from agriculture and waste, reflecting the country's industrial and economic structure during the observed period.

Figure 3: Sectoral contributions to GHG emissions in Botswana, Namibia, Mozambique and South Africa (2010–2022)



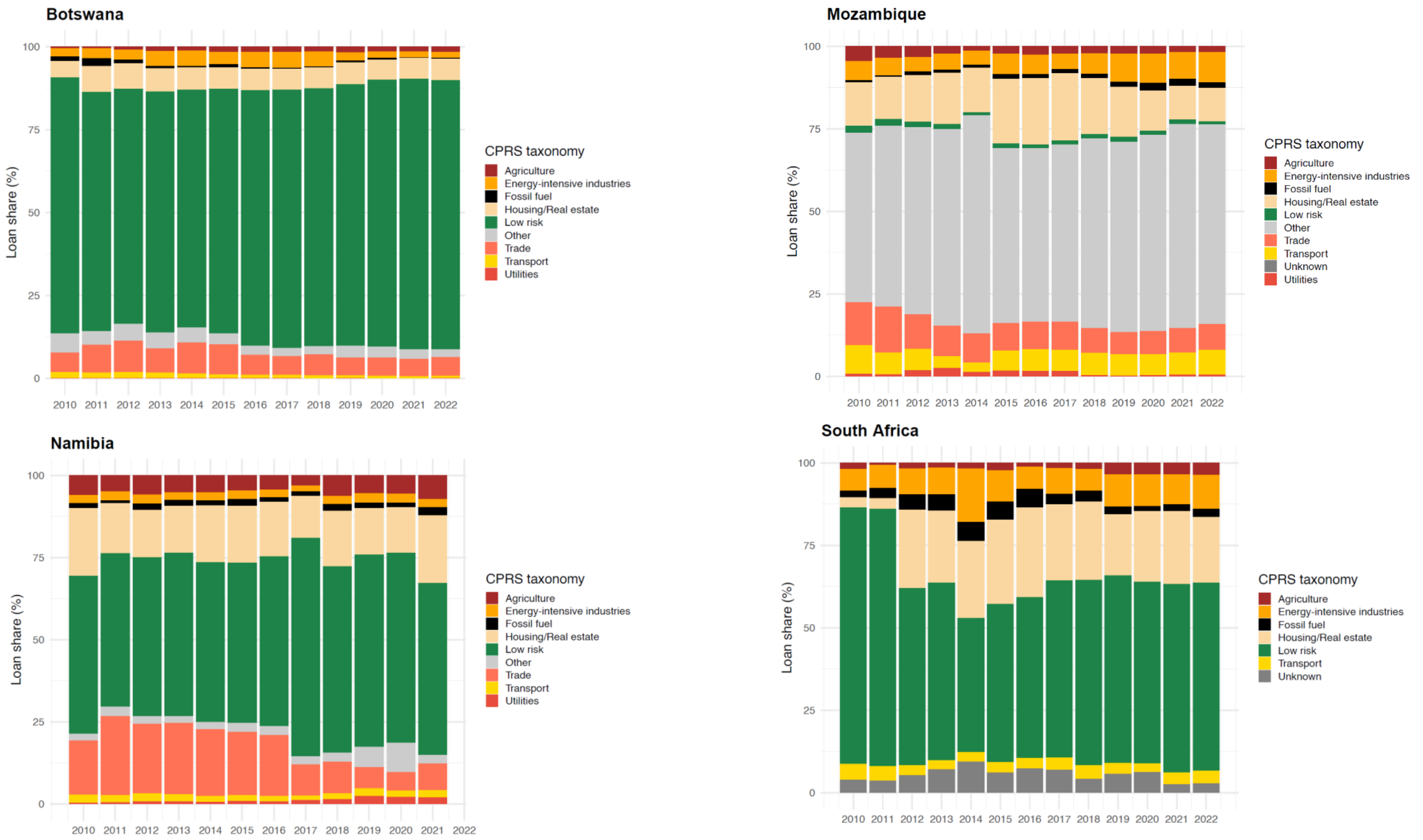
Source: Authors' elaboration on Crippa et al. (2023) data

4.1.2 CPRS classification

We begin by analysing the distribution of loan shares across sectors in Botswana, Namibia, Mozambique and South Africa from 2010 to 2022. The analysis uses sectoral loan allocation data and classifies sectors based on the CPRS taxonomy.[5] The results are presented in Figure 4, which displays the annual loan share of each CPRS category for the four countries.

[5] See section 3.3.1 for a detailed explanation of the CPRS classification and mapping methodology, following Battiston et al. (2017).

Figure 4: Distribution of loan shares across sectors based on the CPRS taxonomy (2010–2022)



Note: Each panel shows sector-level loan share data for Botswana, Namibia, Mozambique and South Africa. Sectors include agriculture, energy-intensive industries, fossil fuels, housing/real estate, low-risk activities, trade, transport, utilities and categories classified as unknown. The stacked bar charts reflect the relative contribution of each sector to the total loan portfolio annually, highlighting the composition and evolution of sectoral lending patterns. *Loan data for Namibia are not available after 2021.*

The results reveal notable cross-country differences in the composition and evolution of loan portfolios, which are shaped by national economic structures and financial sector priorities. In Botswana, the banking system is heavily concentrated in low-risk sectors, with finance and business services consistently representing the majority of loan allocations. Agriculture maintains a small but stable share, while high-risk sectors such as fossil fuels, utilities and energy-intensive industries account for only a minor portion of the portfolio, indicating relatively limited exposure to transition risks.

Namibia shows a broadly similar structure, with loan portfolios dominated by low-risk sectors. However, the share of housing/real estate and utilities is larger than it is for Botswana, suggesting a slightly more diversified but still conservative allocation profile. Despite some year-to-year variation, the sectoral composition remains relatively stable over time.

Mozambique's loan portfolio is markedly more volatile. While low-risk sectors still represent a large share, their relative weight has fluctuated significantly. High-risk sectors, particularly energy-intensive industries and utilities, show periods of sharp increases, especially after 2015. Despite its economic importance, agriculture maintains a limited and flat share of the portfolio, contradicting the notion of a declining trend. A large share of loans categorised as 'unknown' in recent years may indicate inconsistencies in classification or shifts in reporting standards. Overall, the observed variability highlights a potentially heightened exposure to transition risks.

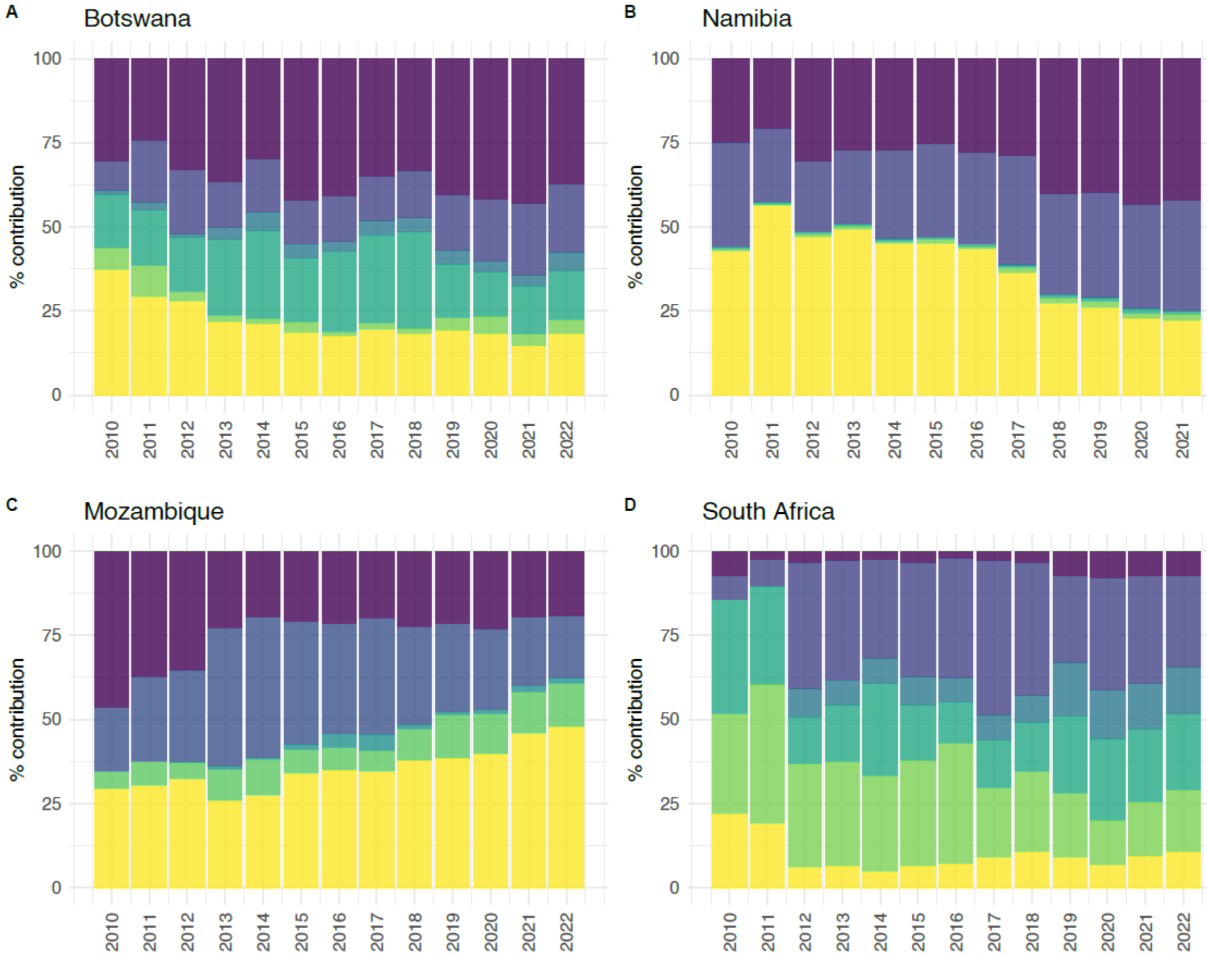
South Africa stands out for its high and sustained exposure to carbon-intensive sectors. Fossil fuels, energy-intensive industries and transport collectively constitute a substantial share of the loan portfolio throughout the period, reflecting the country's industrialised structure and dependence on high-emission sectors. While loans to low-risk sectors are also significant, the continued financial support for high-risk activities underscores structural vulnerabilities and the challenge of aligning financial flows with decarbonisation targets.

Overall, the comparative loan composition shown in Figure 4 highlights the diversity of climate-related financial exposures across countries. Botswana and Namibia display relatively risk-averse financial sector behaviour, with limited engagement in high-emission sectors. In contrast, Mozambique and South Africa face more pronounced transition risk exposures due to their substantial lending to fossil fuels, utilities and energy-intensive activities.

4.1.3 Sectoral contributions to transition risks

Figure 5 presents the annual sectoral contributions to transition risks in Botswana, Namibia, Mozambique and South Africa from 2010 to 2022. These contributions are calculated as the product of each sector’s loan volume and its GHG emissions and are normalised within each year to express sectoral shares as percentages. This methodology integrates financial exposure with emissions intensity, enabling a relative assessment of how different sectors contribute to the financial system’s vulnerability to climate-related transition risks.

Figure 5: Sectoral contributions to transition risks (2010–2022)



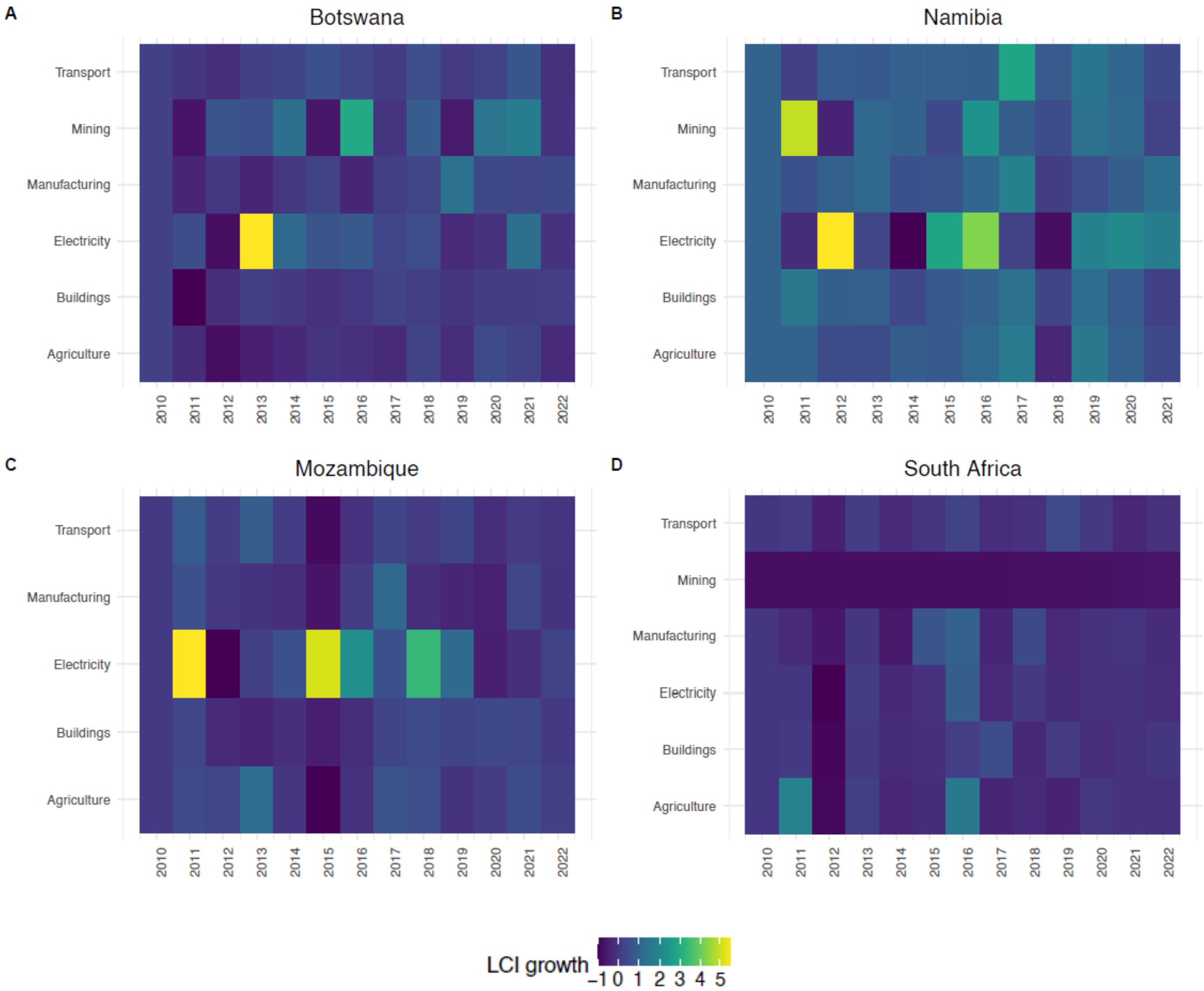
Note: The figure displays the annual sectoral shares of climate-related transition risks in Botswana, Namibia, Mozambique and South Africa. Sectoral contributions are computed as the product of each sector's loan volume and its GHG emissions, then normalised by year to express relative shares. High-risk sectors – such as electricity and manufacturing – dominate across most countries, reflecting structural dependencies on carbon-intensive activities. Other sectors exhibit varying contributions, shaped by differences in economic composition and financial exposure. *Loan data for Namibia are not available after 2021.*

In Botswana (Panel A), electricity, agriculture and transport consistently account for the largest shares of transition risk. Mining and manufacturing exhibit greater year-to-year variability, suggesting episodic changes in sectoral loan allocation or emissions intensity. Namibia (Panel B) displays stable dominance of transport, electricity and mining across the sample period, reflecting persistent carbon intensity and financial relevance. Agriculture and buildings contribute less but remain relatively stable over time, while manufacturing shows moderate fluctuations. In Mozambique (Panel C), electricity contributes the largest share throughout the period, underscoring its centrality in the country's energy system and emissions profile. Manufacturing and transport also play substantial roles, while agriculture and buildings remain smaller contributors but with observable variation over time. South Africa (Panel D) is characterised by a persistent dominance of electricity and manufacturing, consistent with its reliance on coal-based power generation and industrial structure. Mining also contributes significantly, though to a lesser extent. Agriculture, buildings and transport contribute smaller but stable shares, indicating comparatively lower exposure to transition risks.

4.1.4 Loan carbon intensity

Using the LCI framework, we examine the evolution of sectoral carbon intensity growth over time, highlighting differences in financial exposure and emissions dynamics across countries. This analysis provides insights into the structural and economic patterns that underpin climate-related financial risks, offering a basis for more targeted transition strategies. Figure 6 shows year-on-year LCI growth for six major sectors in Botswana (Panel A), Namibia (Panel B), Mozambique (Panel C) and South Africa (Panel D).

Figure 6: Sectoral heatmaps of LCI growth, 2010–2022



Note: Each panel displays the year-on-year percentage change in LCI for major economic sectors across four Southern African countries. LCI growth is computed as the ratio of sectoral GHG emissions to bank loan volumes, capturing how the carbon intensity of financial exposures evolves over time. Bright areas indicate increased carbon intensity, while dark areas reflect reductions. *Loan data for Namibia are not available after 2021.*

Each tile represents the percentage change in LCI for a given sector and year, allowing for the identification of both high-emitting sectors and temporal volatility in their carbon intensity relative to bank lending. In Botswana, LCI growth remains relatively stable across most sectors, with some intermittent spikes in electricity and mining, suggesting episodic shifts in carbon intensity or loan reallocation. Agriculture and transport exhibit moderate and consistent growth, indicating persistent but controlled emissions intensity relative to their credit exposure. Namibia shows more consistent LCI growth in electricity and transport, indicating a sustained carbon intensity in sectors critical to the country's infrastructure. Agriculture and buildings demonstrate lower and relatively flat LCI growth, suggesting limited shifts in emissions or credit composition in those sectors.

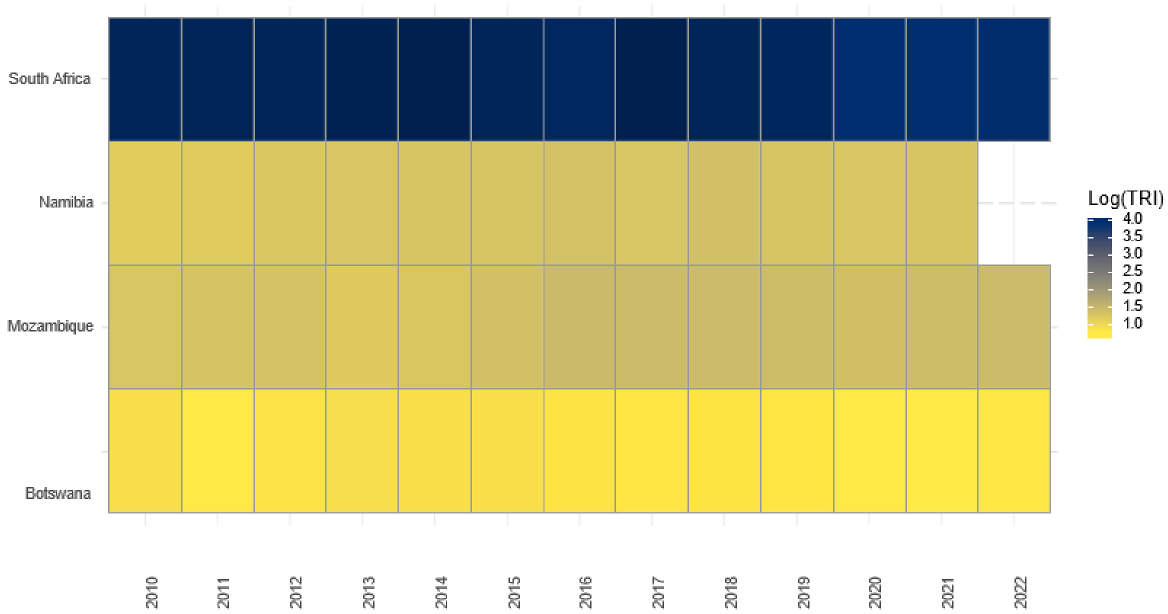
Mozambique displays the most volatile LCI growth patterns, particularly in electricity and manufacturing, where abrupt year-on-year changes reflect dynamic structural or policy changes, possibly linked to investment shifts or energy diversification. Transport and agriculture show more stable, modest growth, consistent with their baseline economic roles. In South Africa, LCI growth is high and persistent in electricity and manufacturing, consistent with the country's coal-dependent energy system and industrial base. Mining also shows elevated LCI growth in several years, reinforcing its dual role as both a major emitter and a credit-intensive sector. In contrast, agriculture and buildings exhibit lower and steadier LCI growth, indicating a limited change in their emissions intensity over the observed period.

4.1.5 Transition risk index

The TRI, defined in section 3.3.3, captures the financial system's exposure to climate-related transition risks by weighting sectoral GHG emissions by the proportion of total loans allocated to each sector.

Figure 7 presents the evolution of the TRI for Botswana, Namibia, Mozambique and South Africa between 2010 and 2022. The TRI is displayed on a logarithmic scale and captures the financial sector's exposure to climate-related transition risks, as determined by the interaction between sectoral loan allocations and GHG emissions. The figure reveals distinct cross-country differences in both the magnitude and temporal dynamics of transition risk exposure. South Africa consistently records the highest TRI values among the four countries throughout the sample period. This sustained elevation suggests that the South African financial sector is significantly and persistently exposed to carbon-intensive activities. While minor year-to-year variation is observed, the overall trajectory remains stable, indicating that structural factors – such as reliance on fossil-fuel-based energy and emissions-intensive industrial sectors – continue to underpin the financial system's vulnerability to transition risks.

Figure 7: TRI by country (2010–2022)

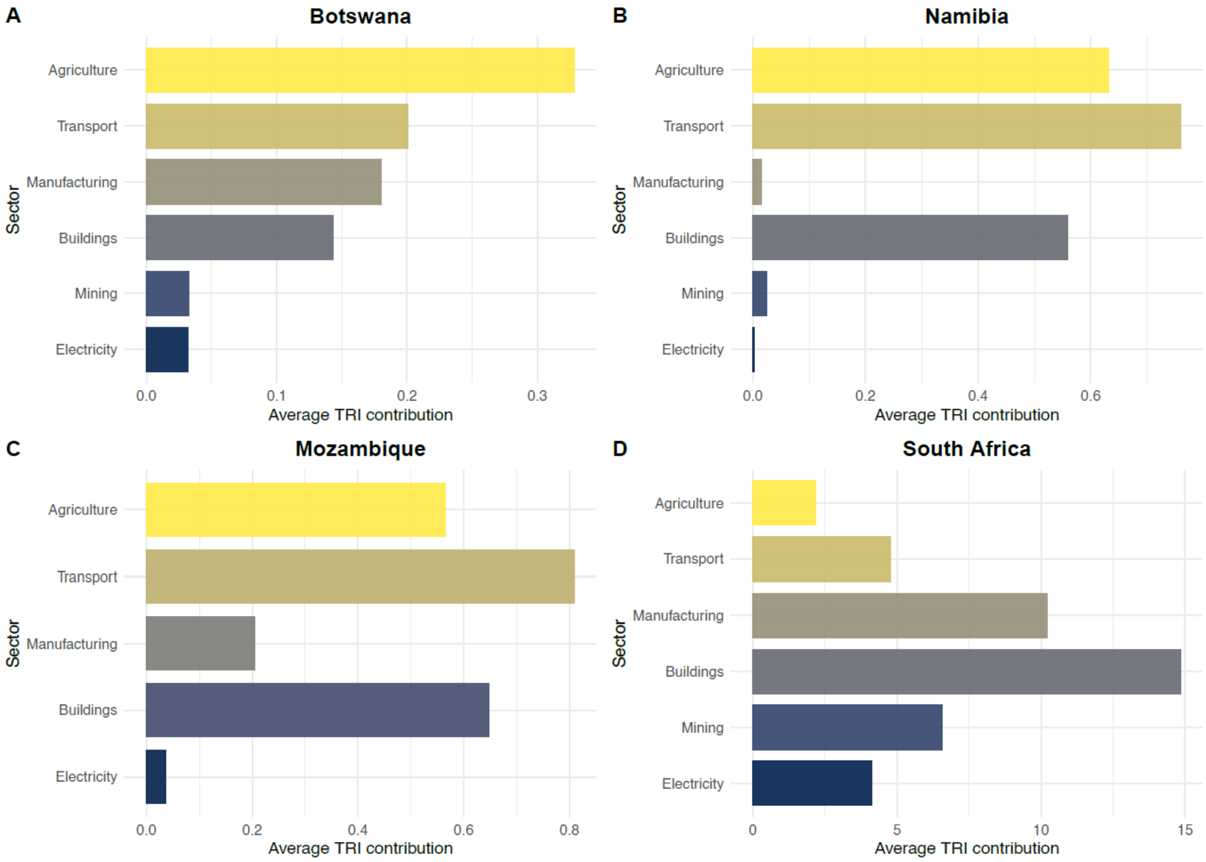


Note: Loan data for Namibia are not available after 2021.

Mozambique exhibits moderate TRI values relative to South Africa, with a relatively stable temporal profile. The absence of abrupt shifts or discontinuities suggests a consistent exposure pattern over time. Although some annual variation is present, the figure does not indicate any significant structural change in the composition of sectoral lending or emissions intensity. Namibia displays comparatively low TRI values over the observed period (2010–2021), with limited interannual fluctuation. The data series ends in 2021, precluding commentary on more recent developments. However, the available evidence suggests that the Namibian financial sector maintains a relatively low exposure to transition risks, potentially due to a more diversified or less emissions-intensive loan portfolio. Botswana registers the lowest TRI values across the sample and exhibits high temporal stability. The consistently subdued index levels imply limited credit exposure to carbon-intensive sectors. The lack of growth over the 12 years supports the interpretation that Botswana's financial system remains relatively insulated from transition-related vulnerabilities.

Figure 8 complements the analysis of TRI dynamics by illustrating the average contribution of major economic sectors to the TRI across Botswana, Namibia, Mozambique and South Africa over the period 2010 to 2022. Sectoral contributions are computed as the product of each sector's share in total loan allocations and corresponding GHG emissions intensity, thereby capturing its relative weight in systemic transition risk exposure.

Figure 8: Average sectoral contribution to the TRI (2010–2022)



Note: Sectoral TRI contributions are computed as the product of each sector's share in total loan allocations and its corresponding GHG emissions. The bars represent the average contribution of each sector to systemic transition risk, highlighting country-specific drivers of climate-related financial exposure. *Loan data for Namibia are not available after 2021.*

In South Africa, the financial sector's exposure is heavily concentrated in *electricity*, *mining* and *manufacturing*, reflecting the economy's structural dependence on coal-based power generation and emissions-intensive industry. In Mozambique, *electricity* also accounts for the largest share of TRI, followed by *manufacturing* and *transport*, suggesting that investments in infrastructure and industrial development shape financial risk. In both Namibia and Botswana, the sectoral composition of TRI is narrower, with *electricity*, *mining* and *transport* accounting for the majority of exposure. By contrast, *buildings* and *agriculture* contribute marginally, indicating a more concentrated risk structure and potentially less diversified exposure to transition dynamics. These findings highlight the importance of sector-specific transition strategies and underscore the need for financial institutions to align credit allocation with decarbonisation pathways, particularly in sectors that dominate exposure to transition risks.

Taken together, Figures 7 and 8 provide a comprehensive understanding of how financial systems in Southern Africa are exposed to transition risks, not only in terms of aggregate levels over time, but also through the specific sectoral structures driving that exposure. This link reveals that sustained transition risk is often structurally embedded in high-emission sectors such as electricity, mining and manufacturing.

4.2 Empirical estimation results

4.2.1 Effects of transition risks on external balance and trade

In this section, we analyse the effects of unanticipated shocks to the TRI on the current account and trade openness. Figure 9 reports the impulse response function, estimated using the identification approach of Caldara et al. (2016), based on a two-variable VAR with two lags and one standard deviation shock to the TRI. The current account balance is of particular interest, as it reflects not only trade in goods and services but also investment income, debt service payments and net public and private transfers. An improvement in the current account balance typically reflects higher exports or investment income, while deterioration may result from increased imports or debt servicing. Trade volume, defined as the sum of exports and imports relative to GDP, increases when either or both components rise.

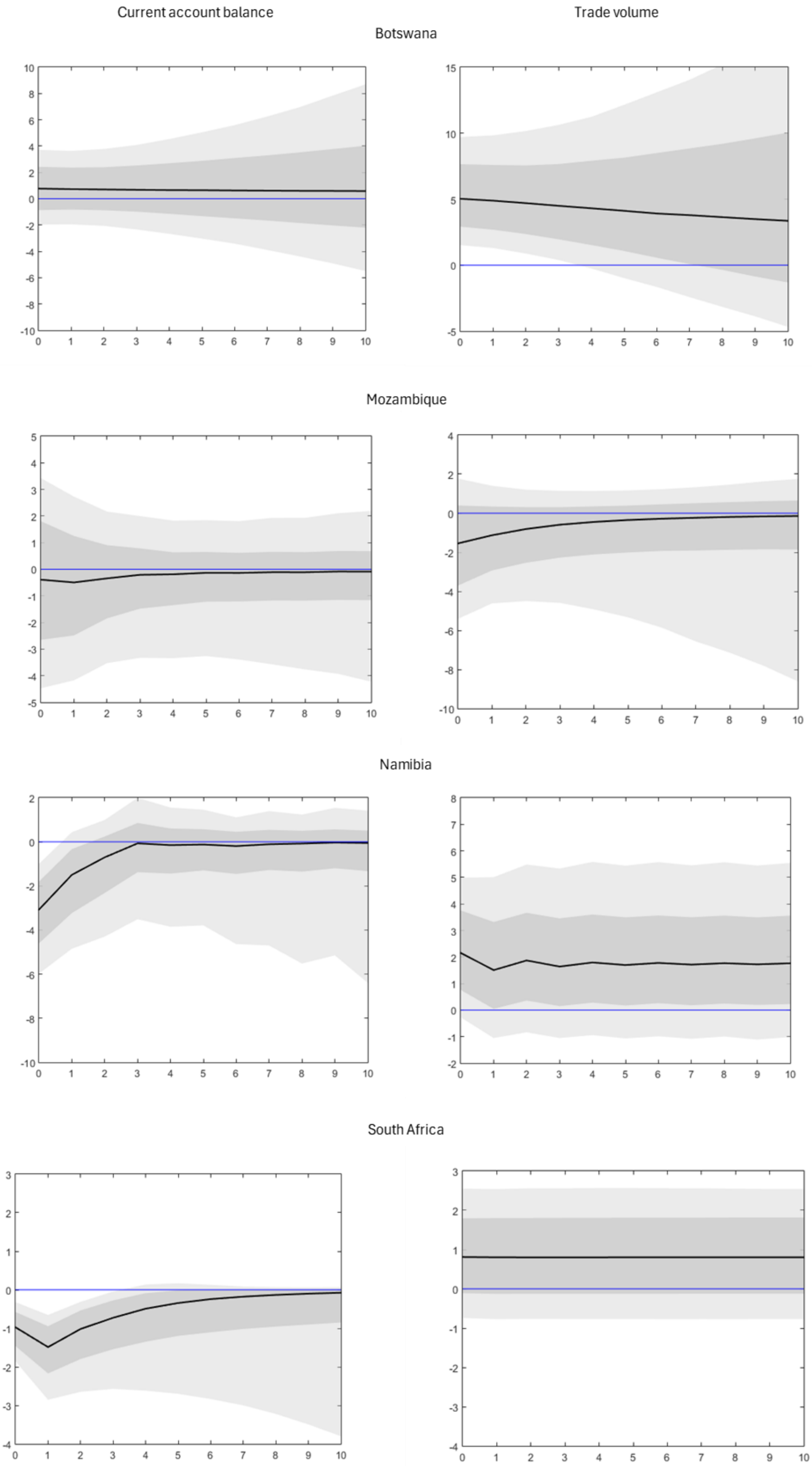
According to Bems et al. (2024), the macroeconomic impact of transition risk shocks depends on the carbon intensity of production. For countries with high carbon intensity, the balance of payments is likely to deteriorate due to such shocks, especially where international investment is involved. If a country’s exports are carbon-intensive, transition shocks can reduce trade openness and weaken the trade balance. Conversely, if a country exports low-emission goods or critical raw materials for the green transition, the trade balance is likely to improve.

The impulse response functions indicate heterogeneity in the external sector response across the four countries. Namibia and South Africa experience a statistically significant, albeit temporary, deterioration in the current account balance following a transition risk shock, with a recovery observable over the medium term. In contrast, Botswana and Mozambique show no statistically significant change in their current account balance, suggesting a degree of resilience to such shocks.

Trade volume responses also vary. Botswana displays a positive and significant increase over time, possibly reflecting the limited role of carbon-intensive exports in its economy. Namibia exhibits a modest but statistically significant increase in trade volume, suggesting short-term gains from realignment in trade flows. Mozambique and South Africa, however, show no statistically significant reaction, as the impulse response functions remain close to zero and confidence intervals overlap throughout the horizon.

Overall, the analysis reveals that the macroeconomic effects of transition risk shocks are heterogeneous across countries, shaped by structural differences in trade composition and carbon intensity. Namibia and South Africa exhibit a statistically significant deterioration in their current account balances following a shock, consistent with higher exposure to carbon-intensive sectors. While Namibia shows signs of recovery over time, the effect in South Africa appears more persistent. In contrast, Botswana experiences a notable increase in trade volume, suggesting greater resilience, potentially due to a more diversified export structure or lower reliance on emissions-intensive goods.

Figure 9: Impulse response functions of the current account balance and the trade volume of selected countries using the identification approach of Caldara et al. (2016)



Note: Impulse responses are calculated for a one standard deviation shock in the TRI. A two-variable VAR is estimated with two lags. The grey bands represent the 68% and 90% confidence intervals.

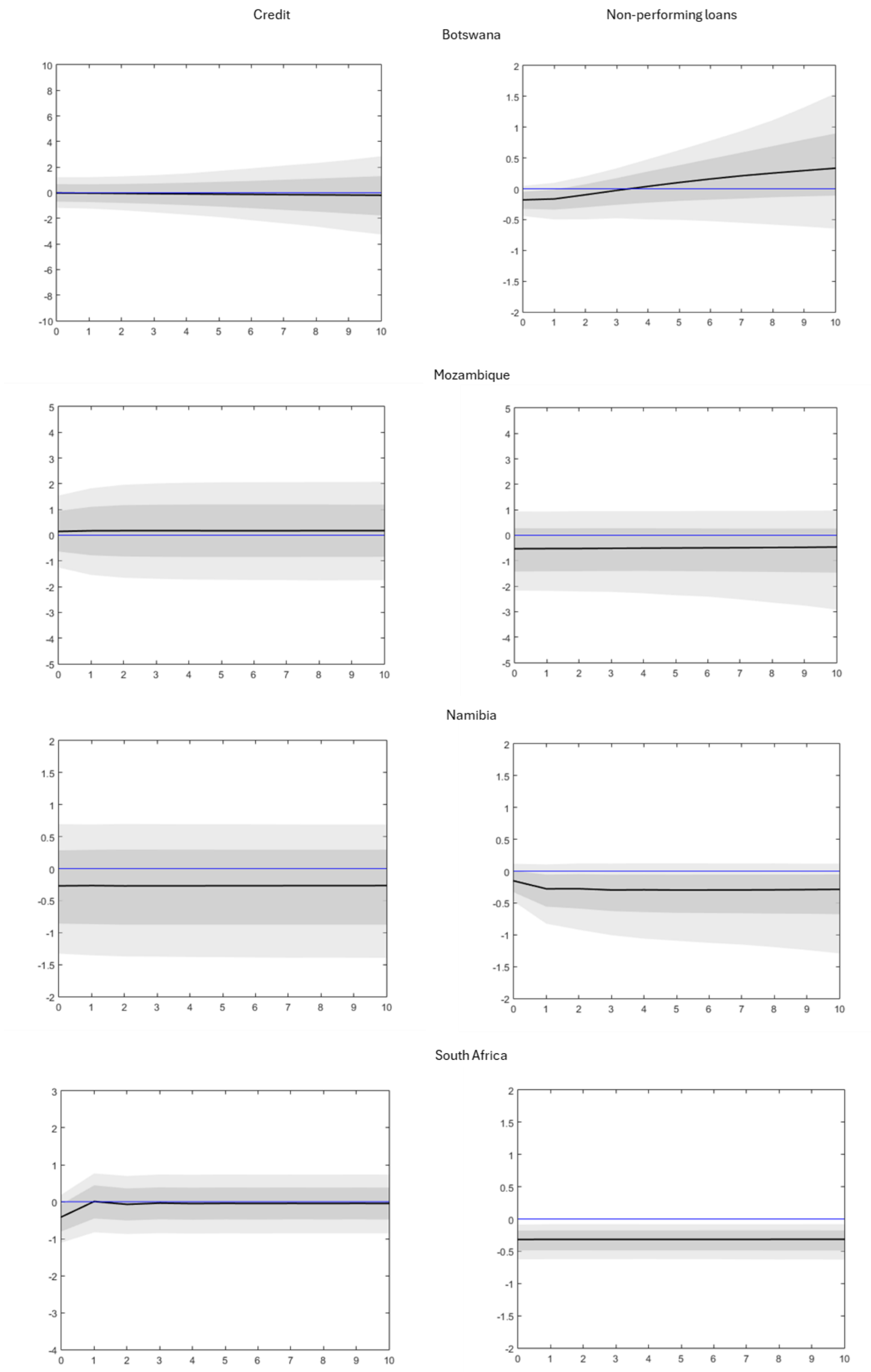
4.2.2 Effects of transition risks on credit and non-performing loans

This section examines the effects of unexpected transition risk shocks on the banking sector, using credit volume and NPLs as endogenous variables. Transition risk shocks are expected to affect financial conditions through their influence on carbon-intensive sectors. In economies where production is carbon-intensive, we may observe a decline in credit supply and a corresponding increase in NPLs, as borrowers face heightened uncertainty and potential structural adjustments.

Compared to the effects on external balance and trade, the responses of credit and NPLs to transition shocks are generally weaker. However, as shown in Figure 10, country-specific differences remain noteworthy.

In Botswana, Mozambique and Namibia, there are no significant effects on credit supply following a transition risk shock, suggesting that credit conditions remain relatively stable in the short run. In South Africa, however, we observe a modest but statistically significant reduction in credit volume after a transition risk shock, implying that banks may respond to increased transition risk by tightening lending, particularly to exposed sectors.

Figure 10: Impulse response functions of the credit and NPLs of selected countries using the identification approach of Caldara et al. (2016)



Note: Impulse responses are calculated for a one standard deviation shock in the TRI. A two-variable VAR is estimated with two lags. The grey bands represent the 68% and 90% confidence intervals.

The dynamics of NPLs are somewhat unexpected. In both Namibia and South Africa, NPLs decline significantly following a transition risk shock. This counterintuitive result may reflect improvements in risk management or a shift in lending portfolios towards less exposed sectors. In Botswana, a significant reduction in NPLs is observed on impact, but the effect dissipates over time. No statistically significant effect is detected in Mozambique.

These findings suggest that banks in the selected countries are not experiencing a surge in credit defaults following transition shocks. On the contrary, NPL ratios appear to decline, while overall credit supply remains stable or only modestly affected. This may indicate that banks are proactively managing their exposures to transition risks without significantly restricting the overall credit volume. To understand the mechanisms that lead to this, an in-depth analysis of lending in these countries would be necessary.

Overall, the results point to a limited and heterogeneous adjustment of the banking sector to transition risk shocks. There are currently no signs that the banking sector is restricting its lending following unexpected shocks from the transition risks. The availability of credit is therefore unlikely to have changed as a result of this risk. While credit supply remains largely unaffected in most countries, the observed decline in NPLs raises questions about the underlying mechanisms, possibly linked to portfolio shifts or improved borrower resilience.[6]

4.2.3 Robustness checks

Given the relatively short time series for transition risk indicators and macrofinancial variables, and the structural assumptions embedded in the baseline identification strategy, we perform a robustness check using an alternative identification approach. Specifically, we estimate a set of BVARs with Normal-Wishart priors and identify shocks via a Cholesky decomposition. In each model, the TRI is ordered first, implying

[6] A more granular, micro-level analysis is required to determine whether these responses contribute to long-term financial stability or merely represent short-term adjustments. We leave this important question for future research.

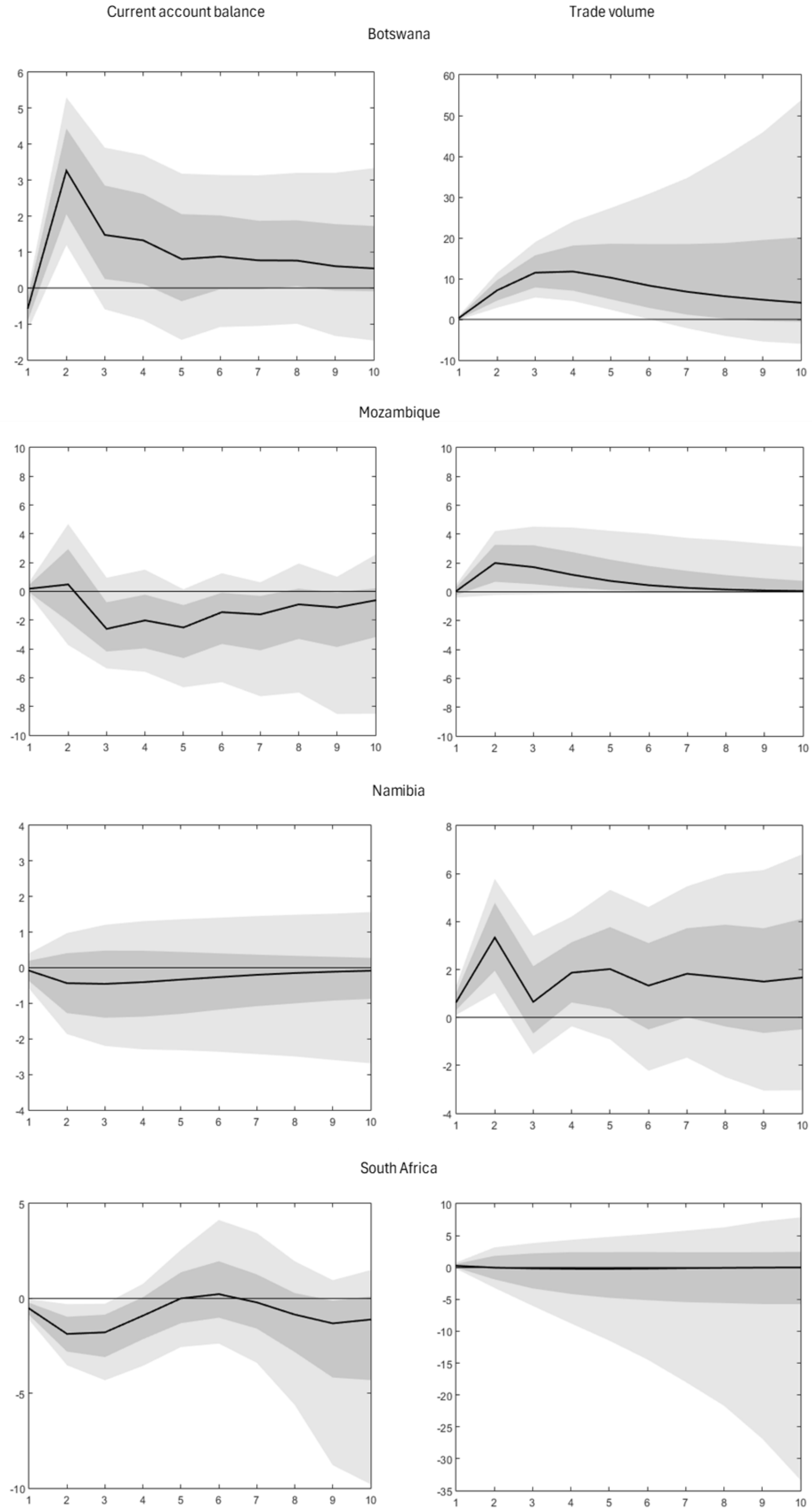
it affects the second variable contemporaneously, but not vice versa. All models are estimated with two lags.

External sector variables. The impulse responses for the current account balance and trade volume (Figure 11) largely confirm the baseline results (section 4.2). Transition risk shocks tend to reduce the current account balance in Mozambique, Namibia and South Africa. Botswana is an exception, showing a statistically significant short-term improvement in the current account. Trade volume generally increases in response to transition shocks, with particularly strong effects observed in Botswana and moderate positive responses in the other three countries.

Banking sector variables. The responses of credit and NPLs (Figure 12) show less consistency with the baseline results. Notably, we observe a positive and statistically significant response of credit in both Botswana and South Africa, effects not identified under the Caldara et al. (2016) sign-restriction approach. This suggests that lending may initially expand in some countries despite increased transition risks, potentially reflecting forward-looking adjustments or compositional effects in credit allocation. The responses of NPLs remain muted and statistically insignificant across countries, consistent with the baseline findings.

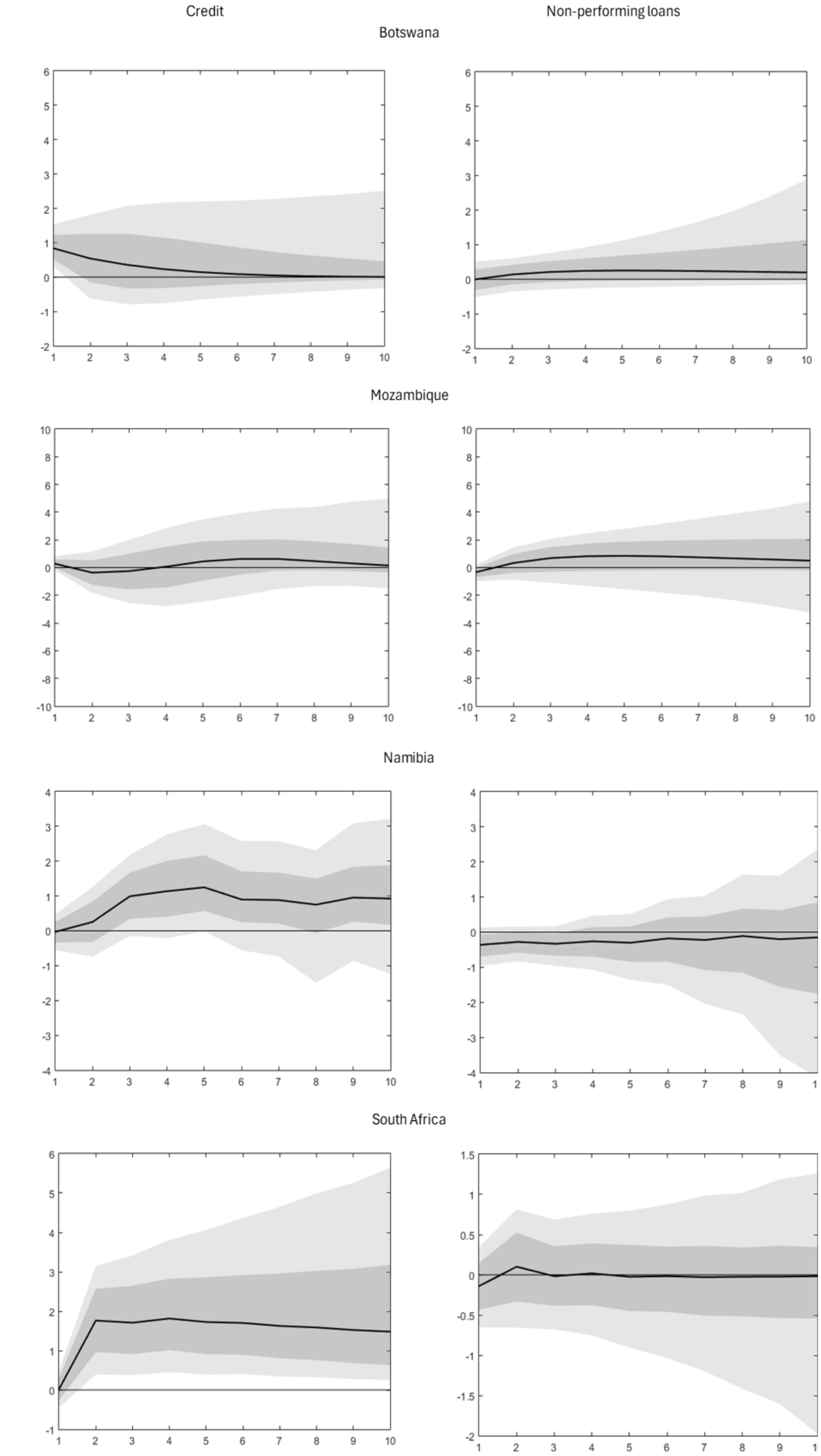
Overall, the robustness analysis confirms the main directional effects for the external sector variables, while highlighting some sensitivity in the financial sector responses, particularly for credit supply.

Figure 11: Impulse response functions of the current account balance and trade volume of selected countries using a Cholesky decomposition



Note: Impulse responses are calculated for a one standard deviation shock in the TRI. A two-variable VAR is estimated with two lags. The grey bands represent the 68% and 90% confidence intervals.

Figure 12: Impulse response functions of the credit and NPLs of selected countries using a Cholesky decomposition



Note: Impulse responses are calculated for a one standard deviation shock in the TRI. A two-variable VAR is estimated with two lags. The grey bands represent the 68% and 90% confidence intervals.

5. Conclusion

This paper has examined the exposure of financial systems in Botswana, Namibia, Mozambique and South Africa to climate-related transition risks by analysing GHG emissions, sectoral loan allocations and macrofinancial responses to transition shocks.

The structural analysis reveals differences across the four countries. South Africa emerges as the most vulnerable, primarily due to its sustained reliance on coal-based energy and high concentration of credit in carbon-intensive sectors. Botswana and Namibia, while exhibiting lower aggregate emissions, show specific sectoral vulnerabilities – particularly in agriculture and transport. Mozambique's exposure is more volatile, reflecting instability in its sectoral lending patterns. The LCI analysis corroborates these findings: carbon-intensive sectors dominate credit portfolios in South Africa and, to a lesser extent, in Namibia and Mozambique. The TRI similarly confirms South Africa's elevated exposure, underscoring the urgency of reallocating financial flows towards low-carbon sectors.

These findings are consistent with recent estimates from the SARB. Monnin, Sikhosana and Singh (2024) show that about 35% of total corporate credit exposure is allocated to transition-sensitive sectors, rising to 60% when the buildings sector is included. Their analysis identifies the coal value chain as a central vulnerability and confirms that transition risks are not only significant in aggregate terms but also unevenly distributed across financial institutions, particularly among smaller banks and foreign branches. This reinforces our conclusion that South Africa faces elevated systemic risk relative to its regional peers and underscores the urgency of realigning financial flows away from carbon-intensive sectors.

The dynamic analysis using country-specific BVAR models further shows how transition risks propagate through macroeconomic and financial channels. Impulse response functions indicate that current account balances tend to deteriorate in Mozambique, Namibia and South Africa following a transition risk shock, whereas Botswana experiences a short-term improvement. Trade volumes increase in Botswana and, to a lesser extent, Namibia – suggesting that some economies may benefit from realigning their trade patterns towards lower-carbon sectors. However, trade responses in Mozambique and South Africa are not statistically significant.

The responses of the banking sector are comparatively muted and heterogeneous. Credit supply remains broadly stable in the baseline models but increases modestly in Botswana and South Africa under alternative identification strategies. These results may reflect anticipatory investment behaviour or compositional shifts in lending. Notably, NPL ratios do not rise; instead, they exhibit modest declines in some countries, raising questions about potential portfolio reallocation or borrower resilience. Overall, while credit availability does not appear to be restricted by transition shocks, further investigation is needed to understand the mechanisms behind the observed NPL dynamics.

Empirical analyses thus far suggest that the effects of transition risk shocks on trade and banking sector stability are limited but not negligible. The deterioration of the current account in Namibia and South Africa highlights a potential vulnerability that may, over time, constrain international solvency.

Overall, the findings suggest that transition risks are already shaping external balances and sectoral credit structures, even if signs of broader financial instability have not yet materialised. This presents a critical window of opportunity for financial regulators and central banks to strengthen transition-aligned credit guidance, enhance risk monitoring frameworks and proactively redirect financial flows away from high-emission sectors, particularly in countries like South Africa, where systemic exposure remains significant.

Emerging global developments such as the EU's Carbon Border Adjustment Mechanism and the escalating risk of stranded assets in fossil-fuel-intensive industries are likely to place additional pressure on financial stability. For carbon-intensive exporters – especially South Africa, but also Botswana, Namibia and Mozambique – the EU's Carbon Border Adjustment Mechanism may erode trade competitiveness, reduce export revenues, and heighten corporate and sovereign credit risks. Concurrently, increased investor demand for ESG-aligned assets and the tightening of international climate policy frameworks may further test the resilience of domestic financial systems.

To mitigate these risks, a forward-looking and adaptive regulatory framework is essential. Enhancing climate-related financial policies, such as climate stress testing, differentiated capital requirements for high-carbon exposures and mandatory disclosure of carbon-intensive assets, can significantly improve preparedness for a disorderly transition. Incorporating transition risk into macroprudential surveillance will be critical for identifying and managing systemic vulnerabilities linked to concentrated exposures in high-emission sectors.

In addition to strengthening prudential regulation, targeted credit reallocation tools are needed to better align financial flows with national decarbonisation objectives. Instruments such as green lending guidelines, sustainable bond frameworks and blended finance vehicles can facilitate a shift in capital towards low-carbon sectors and promote economic diversification. Close coordination between financial regulators, central banks and fiscal authorities will be vital to harmonise domestic policies with evolving global standards.

While this paper provides a first-order assessment of the macrofinancial implications of transition risks, future research should investigate sectoral transmission mechanisms in greater depth. In particular, the use of network-based models or multi-sector VAR frameworks could shed light on how transition shocks diffuse across financial institutions and interlinked supply chains, deepening our understanding of systemic climate-financial vulnerabilities in emerging economies.

Annexures

A. Methodology

A.1 Data availability and collection

Owing to the lack of standardised central bank information on the sectoral distribution of banks' assets, our methodology included data from the annual reports of major commercial banks in two of the chosen countries, namely Mozambique and South Africa. Table A1.1 details the banks selected for analysis in each country. Given the available data, we aimed to ensure a comprehensive analysis of the banking sectors' resilience to risks associated with the low-carbon transition. However, reviewing the banks' reports revealed that sectoral loan allocation information was not consistently available for all major banks in these countries. While this represents a limitation of the analysis, it reflects the best approach possible given the constraints in data availability.

Table A1.1: Biggest banks in South Africa and data coverage

Country	Top five banks	Years available
South Africa	Standard Bank	2013–2022
	Nedbank	2010–2022
	Capitec Bank[1]	2010–2022
	Absa[2]	2010–2022
	FirstRand	2010–2022

Note:

[1] Despite the good coverage and availability of reports, sectoral loan data were not disclosed. Therefore, information from Capitec Bank was not included in the analysis.

[2] Despite the good coverage and availability of reports, sectoral loan data were not disclosed. Therefore, information from Absa Bank was not included in the analysis.

The retrieval of sectoral loan data from bank reports required a meticulous and multi-step process. To optimise efficiency, we initially used GPT-4o-mini, a generative artificial intelligence tool developed by OpenAI. This transformer-based model, derived from the GPT-4 architecture, is designed for efficiency, balancing performance with computational resource requirements, making it well suited for extracting tables from text files.

To guide the model, we used the following prompt: "Please extract data related to sectoral loans from the document. Focus on tables or sections providing a breakdown of loan amounts by economic sectors, with sector names (e.g. agriculture, manufacturing, financial services) and corresponding loan amounts for each sector. Save the data in a table format, clearly distinguishing sector names and years. If multiple years are provided, ensure each year is denoted clearly, each as a separate column." This ensured the extracted information was precise and organised.

However, GPT-4o-mini's input limit of 128 000 tokens posed challenges, as many bank reports exceeded this threshold. To address this, we implemented preprocessing steps such as converting text to lowercase, removing page numbers, condensing excess spaces, and eliminating standard English stopwords (e.g. 'a', 'the', 'and', 'if'). These steps reduced token counts without compromising semantic meaning. For reports that still exceeded the token limit, data extraction was performed manually.

The manual process involved systematically downloading annual reports for each bank across all available years. Due to inconsistent reporting formats and styles, each report was manually reviewed to identify sectoral loan data. While some reports provided the data in tables or appendices, others embedded it within narratives, adding complexity to the extraction process. Variations in terminology, disclosure practices and level of detail further complicated the task. Despite these challenges, the manual approach ensured the creation of a comprehensive and reliable dataset, reflecting a significant commitment to data quality and robust analysis.

A.2 Economic sectors taxonomy homogenisation

Sectoral alignment of GHG emissions data with loan data

GHG data at the sectoral level are retrieved from Crippa et al. (2023). The analysis uses the following sector definitions:

- **Power industry:** Power and heat generation plants (public and auto producers).
- **Industrial combustion:** Combustion for industrial manufacturing.
- **Buildings:** Small-scale non-industrial stationary combustion.
- **Transport:** Mobile combustion, including road, rail, ship and aviation.
- **Agriculture:** Agricultural soils, crop residue burning, enteric fermentation, manure management and indirect N_2O emissions from agriculture.
- **Fuel exploitation:** Production, transformation and refining of fuels.
- **Processes:** Industrial processes, including emissions from the production of cement, iron and steel, aluminium, chemicals and solvents.
- **Waste:** Solid waste disposal and wastewater treatment.

Sectoral loans data, which are publicly available on the Bank of Botswana's website, cover a broad spectrum of economic sectors, including central and local government, parastatals, households, agriculture, mining, manufacturing, electricity and water, construction, trade, transport and communications, finance, business services, real estate, and resident and non-resident categories.

To ensure alignment between the GHG data and the loan data, a sector-matching process was performed. Table A2.1 outlines the correspondence between sectors in the two datasets and their recoding labels used for analysis. Sectors in the GHG data without a match in the loans data (e.g. 'fuel exploitation' and 'waste') are excluded from the analysis.

Table A2.1: Botswana: correspondence between GHG data sectors, loans data sectors and recoding for the analysis

GHG data sectors	Loans data sectors	Recoding in analysis
Agriculture	Agriculture	Agriculture
Buildings	Real estate	Buildings
Fuel exploitation	No match	Excluded
Industrial combustion	Manufacturing	Manufacturing
Power industry	Electricity and water	Electricity
Processes	Mining	Mining
Transport	Transport and communications	Transport
Waste	No match	Excluded

Note: Sectors without a match in the loan data are excluded from computations.

Table A2.2: Mozambique: correspondence between GHG data sectors, loans data sectors and recoding for the analysis

GHG data sectors	Loans data sectors	Recoding in analysis
Agriculture	Agriculture	Agriculture
Buildings	Real estate	Buildings
Buildings	Construction	Buildings
Fuel exploitation	No match	Excluded
Industrial combustion	Manufacturing	Manufacturing
Power industry	Utilities	Electricity
Processes	No match	Excluded
Transport	Transport	Transport
Waste	No match	Excluded

Note: Sectors without a match in the loan data are excluded from computations.

Table A2.3: South Africa: correspondence between GHG data sectors, loans data sectors and recoding for the analysis

GHG data sectors	Loans data sectors	Recoding in analysis
Agriculture	Agriculture	Agriculture
Buildings	Building, property development	Buildings
Buildings	Property finance/real estate	Buildings
Fuel exploitation	Mining	Fossil fuel
Industrial combustion	Manufacturing	Manufacturing
Power industry	Electricity	Electricity
Processes	Mining	Mining
Transport	Transport	Transport
Waste	No match	Excluded

Note: Sectors without a match in the loan data are excluded from computations.

Mapping sectors in loan data to CPRS taxonomy

To assess the exposure of loan data by sectors to climate-related transition risks, the sectors in the dataset were mapped to high-risk categories as defined by the CPRS framework. The mapping process is summarised in the table below.

Table A2.4: Sector mapping to CPRS high-risk categories

Sector in central bank report	Mapped CPRS category
Agriculture	Agriculture (high risk)
Mining	Fossil fuel
Manufacturing	Energy-intensive industries
Electricity, water	Utilities
Transport, communications	Transport
Construction	Housing/real estate
Real estate	Housing/real estate
Trade	Trade
Finance	Low risk
Business services	Low risk
Government central	Low risk
Government local	Low risk
Households	Low risk
Parastatals	Other
Business resident	Low risk
Business non-resident	Low risk
Other	Other

The mapping reclassifies sectors based on their alignment with the CPRS framework, identifying high-risk categories such as *fossil fuel*, *energy-intensive industries* and *utilities*. Sectors classified as *low risk* or *other* are deemed less exposed to climate-related transition risks. This categorisation facilitates the analysis of financial sector exposure to transition risks across various economic activities.

Table A2.5: Sector classification by country and CPRS taxonomy

Country	Sector	CPRS taxonomy
Mozambique	Agriculture	Agriculture
	Manufacturing	Energy-intensive industries
	Utilities	Energy-intensive industries
	Transport	Transport
	Construction	Housing/real estate
	Real estate	Housing/real estate
	Services	Low risk
	Consumer goods/services	Low risk
	Other	Other
Namibia	Agriculture	Agriculture
	Mining	Fossil fuel
	Manufacturing	Energy-intensive industries
	Electricity, water	Utilities
	Transport, communications	Transport
	Construction	Housing/real estate
	Real estate	Housing/real estate
	Trade	Trade
	Finance	Low risk
	Business services	Low risk
	Government central	Low risk
	Government local	Low risk
	Households	Low risk
	Parastatals	Other
	Business resident	Low risk
	Business non-resident	Low risk
	Other	Other
South Africa	Agriculture	Agriculture
	Banks	Low risk
	Building, property development	Housing/real estate
	Manufacturing	Energy-intensive industries
	Electricity	Energy-intensive industries
	Mining	Fossil fuel
	Government, Land Bank, public authorities	Low risk
	Households	Low risk
	Transport	Transport
	Property finance/real estate	Housing/real estate

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Country	Sector	CPRS taxonomy
	Retail	Low risk
	Services, insurance	Low risk
	Wholesale	Low risk
	Other	Other
Botswana	Agriculture	Agriculture
	Mining	Fossil fuel
	Manufacturing	Energy-intensive industries
	Electricity, water	Utilities
	Transport, communications	Transport
	Construction	Housing/real estate
	Real estate	Housing/real estate
	Trade	Trade
	Finance	Low risk
	Business services	Low risk
	Government central	Other
	Government local	Other
	Households	Low risk
	Parastatals	Other
	Business resident	Low risk
	Business non-resident	Low risk
	Other	Other

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