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Designing a macroprudential capital buffer for climate-related risks

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Abstract

Amid the growing financial vulnerabilities posed by climate change, we investigate macroprudential capital buffers to mitigate systemic risks and increase the resilience of the banking sector. Leveraging granular data and state-of-the-art stress testing methods, we quantify potential bank losses attributed to climate-related transition risks. Focusing on short-term transition scenarios, we document a significant variance among banks in their risk exposure, with the most exposed institutions being those characterized by lower excess capital. Subsequently, we introduce a methodological framework for tailoring bank-specific buffer requirements to cover these losses, offering macroprudential authorities a practical method for calibrating climate-related macroprudential capital buffers, complementing microprudential policies. While we focus our application on transition risks, the framework can be extended to capture all climate risks in general. The study demonstrates the potential of macroprudential capital buffers to mitigate potential climate-related losses and contributes to the understanding of the appropriate prudential policy response to these challenges.

Keywords: macroprudential policy, climate change, transition risk, climate risk

JEL Codes: E61, G21, G28, Q54

Non-technical summary

In recent years, the systemic nature of climate-related risks and their potential threat to financial stability have increasingly been recognized. In this context, prudential authorities have the responsibility to ensure that financial institutions are well-positioned to absorb the potential materialization of such a systemic shock without detrimental consequences for the broader financial system and the supply of credit to the real economy. Despite a growing recognition in the academic literature and policy discussions of the need for a dedicated macroprudential policy response (FSB, 2022; Carattini et al., 2023), research on the concrete design and implementation of macroprudential policy tools to address climate-related risks remains scarce. Our paper contributes to this debate along two important dimensions.

First, we provide novel estimates of the magnitude of climate transition risks for euro area banks. To this end, we build on the second ECB top-down climate stress test to project losses due to transition risk for 107 euro area significant institutions over the 2023-2025 period. Starting from granular loan-level data, we project annual losses on banks' corporate loan, household loan and corporate debt securities portfolios, both within and outside the euro area. We isolate losses due to additional transition efforts that are needed to reach net-zero emissions by 2050 from the ones originating from climate policies currently in place and broader macroeconomic developments. We document a large dispersion in terms of banks' exposure to transition risk, with the highest exposures concentrated in the more vulnerable banks, highlighting the importance of this risk from a financial stability perspective.

Second, we propose a calibration methodology for a macroprudential capital buffer which allows to address the build-up of climate-related systemic risks in the banking sector. The proposed calibration methodology assigns different systemic risk buffer requirements to banks in different buckets depending on each bank's exposure to the estimated climate risks. While we apply the calibration method to the aforementioned transition risk scenario, our general framework can be used flexibly in broader applications, targeting transition and/or physical risks more generally. In the baseline calibration exercise, we show that the proposed capital buffer requirement would adequately cover euro area banks' exposures to transition risk. We also discuss alternative calibration approaches which allow for a flexible implementation by macroprudential authorities, depending on their specific needs. We finally discuss the limitations of the proposed methodology and avenues for future research.

This paper contributes to the debate on the optimal policy mix to address climate-related systemic risks, and in particular to the growing literature on the prudential response to these risks in the banking sector. Our findings highlight the potential systemic relevance of climate risks, while the proposed methodology demonstrates the potential of macroprudential capital buffers to mitigate climate-related losses. The paper also aims to address some of the challenges to the design of a macroprudential capital buffer for climate risks highlighted by the literature: first, by building on a state-of-the art climate stress test approach, the methodology allows to address the largely forward-looking nature of climate risks. Second, by using granular data on transition risk exposures, it aims to minimize possible adverse effects on transition financing. Third, by adopting a bucketing approach, it aims to maximize the efficiency of the measure while minimizing its operational complexity. Overall, this paper makes a significant step towards operationalizing macroprudential capital buffers for climate-related risks, and can inform prudential authorities' reflections on how to concretly implement macroprudential tools to address the build-up of these risks.

1 Introduction

In the context of growing recognition of the risks posed by climate change to the financial sector and the broader economy, prudential authorities have to face the complex challenge of devising the appropriate policy response. Climate-related risks, encompassing both physical impacts and the challenges associated with transitioning to a low-carbon economy, have the potential to introduce significant systemic vulnerabilities within the banking sector (BCBS, 2021; Carattini et al., 2023). It is the responsibility of prudential authorities to ensure that banks are well-prepared to withstand the increasing climate-related risks that could impact their operations and portfolios. Global regulators have highlighted the urgency of integrating climate risk considerations within the regulatory framework to better assess and mitigate financial vulnerabilities, and have raised the prospect of using macroprudential tools to address systemic aspects of climate-related risks (FSB, 2022). Yet, despite the growing consensus on the systemic features of climate risks, the discussion on the concrete implementation of macroprudential tools for climate risk is only incipient.

This paper explores how climate risks should be accounted for in the regulatory framework, providing an analysis of how macroprudential capital buffers can be tailored to effectively address the systemic aspects of these specific risks. The premise of the analysis is that climate-related risks are likely to represent a systemic risk because of their unique features (ECB-ESRB, 2023): (1) they are largely irreversible once they materialize and the related losses would not be reabsorbed when the shock recedes; (2) their concentration and correlation reduces the potential for risk diversification and the ability of private insurance to provide coverage; (3) the non-linearity of climate change effects increases the likelihood of tail-events; (4) the complex interactions, as well as the feedback between transition and physical risks make these risks hard to manage within conventional risk-management relying on expected losses; (5) uncertainty over the scale and timing of climate risk materialization, and reliance on imperfect historical data may lead to risk underestimation, contributing to an excessive build-up of risks and procyclical financing decisions. These unique features are compounded by classic systemic risk channels which may amplify and spread the effects of climate-related shocks. For example, a sudden surge in carbon prices driven by an accelerated transition, could increase not only the likelihood of individual firms' distress, but also the chance that the default of one company leads to the default of another. Firms' assets may unexpectedly lose their value due to sudden transition policies, reducing the value of available collateral for corporate loans and increasing corporate losses. This stress would eventually affect the banking sector via a system-wide deterioration in credit risk, and particularly acute vulnerabilities in those banks most exposed to high-risk sectors. The sudden reassessment of risks might then spread quickly to other segments as overlapping portfolios increase the likelihood of simultaneous distress of several institutions: a strong price correction may spread common losses across different market participants and result in contagion-induced deleveraging pressure, providing a channel for mark-to-market losses to spread between different market segments (ECB-ESRB, 2022).

Among the possible macroprudential tools available to address climate-related systemic risks, this paper focuses specifically on the systemic risk buffer (SyRB).[1] This instrument, which is part of the toolkit of EU macroprudential authorities, has been identified as a potentially well-suited tool to address climate systemic risks (ESRB, 2023; EBA, 2023b). Starting from an application targeting the transition risk dimension of climate change in the euro area banking sector, we propose a uniform methodological framework to calibrate the SyRB for climate purposes. Our analysis is based on a state-of-the-art climate stress test approach, which allows to address the largely forward-looking nature of climate risks and to calibrate the prudential response based on a severe, but realistic, scenario where systemic climate risks materialize. Our paper positions macroprudential capital buffers as a key instrument for authorities to consider in safeguarding the banking sector against the systemic challenges posed by climate change, and emphasizes the importance of proactive regulatory measures in preparing the banking sector for the climate-related risks of the future.

Using granular loan-level data for all significant banks in the euro area, we first derive banks' losses in climate stress scenarios by extending the methodology built for the ECB's second top-down economy-wide climate stress test (Emambakhsh et al., 2023). To obtain comprehensive estimates of transition risk losses, we cover banks' corporate loan, household loan, and corporate

[1] The SyRB can be employed in the European Union to address systemic risks that are not covered by microprudential regulation or by other macroprudential capital buffers. According to EU law, the level of the SyRB may vary across institutions or sets of institutions as well as across subsets of exposures (see ESRB (2017) for additional details).

debt securities portfolios, both within and outside the euro area. Focusing specifically on short-term transition risk scenarios, we translate changes in corporate and household probabilities of default (PDs) into projected bank-level losses. We isolate losses due to additional transition efforts that are needed to reach net-zero emissions by 2050 from the ones originating from currently implemented climate policies and broader macroeconomic developments. Over the 2023-2025 period, we find that an unanticipated acceleration of the transition leads to an increase in projected losses of approximately 52 Bn EUR for euro area significant institutions (SIs), corresponding to 0.60% of aggregate risk-weighted assets (RWA). Moreover, we document a large dispersion across banks in terms of their exposure to transition risk, with the highest exposures situated in banks with lower excess capital, which is used as a proxy to identify the most vulnerable banks. This highlights the importance of this matter from a financial stability perspective. While our analysis provides an important step forward in the assessment of the potential impact of climate-related risks on financial stability, the projected losses should be interpreted as a lower bound given the focus on transition risk (abstracting from physical risk) and the absence of some systemic risk channels, such as second-round effects, in the stress test model and scenarios. Future improvements in stress testing will allow to capture additional systemic risk channels through which climate-related shocks may propagate.

In the second step, based on the projected transition risk losses, we calibrate bank-specific buffer requirements using a bucketing approach. Motivated by the large dispersion in banks' exposure to transition risk, we propose a multiple-rate structure, whereby banks are allocated to different risk buckets with differentiated buffer rates based on their projected losses, instead of a single rate applied to all banks. In the baseline calibration approach, we consider a one-to-one mapping of projected losses into SyRB requirements, which leads to a 50 bps requirement for 56 banks, while 18 banks receive a SyRB requirement of 100 bps or more. For the remaining 33 banks in the sample, we assume that their projected losses do not warrant a SyRB requirement. Subsequently, we present the results under alternative calibration approaches and discuss the implied policy trade-off. Robustness checks confirm that the proposed SyRB methodology delivers comparable outputs when changing sample and time horizon. Importantly, back-of-the-envelope calculations of the impact of the proposed buffer on credit growth based on prevailing estimates in the literature, suggest that the impact of the higher capital requirements on bank lending would be modest if the buffer was introduced in non-stressed times.

The contribution of our paper is two-fold. First, we provide a novel assessment of the impact of climate-related risk on financial institutions and financial stability, focusing on short-term transition risks in the euro area banking system, which contributes to the ongoing academic and policy debate on the systemic relevance of climate-related risks. Second, we propose a concrete calibration methodology for a climate-risk application of the SyRB which could be adapted and used by macroprudential authorities and lead to a harmonized approach in deploying the SyRB to tackle climate risks. While this paper's application focuses on transition risk, the proposed framework can also be applied to address the physical risk dimension of climate change, and its flexibility allows macroprudential authorities to benefit from future improvements and extensions in stress testing models and scenarios.

The remainder of the paper is organized as follows. In Section 2, we discuss the current policy context around macroprudential policy targeting climate-related systemic risk, as well as the positioning of the paper in the existing academic literature. In Section 3, we present our methodology, followed by a description of the results in Section 4. Section 5 performs robustness checks and extensions of the baseline approach. Finally, Section 6 concludes the paper.

2 Policy context and literature overview

2.1 Policy context

The discussion surrounding the inclusion of climate-related risks in the prudential framework is gaining increasing prominence in the global financial regulatory landscape. The emerging consensus acknowledges that the financial sector plays a pivotal role in transitioning to a sustainable, low-carbon economy, while simultaneously facing risks from climate-related events, which have the potential of being systemic (BCBS, 2021; FSB, 2022). The current debate centers on assessing the magnitude of physical and transition risks on financial stability, and whether and how to effectively integrate climate risks into the prudential framework. The distinct characteristics of climate risks, particularly their forward-looking nature, and the challenges these pose to prudential responses, have been discussed by major international financial institutions and global standard setters.

As part of the discussion on incorporating climate-related risk considerations into the prudential framework, macroprudential tools, including capital buffers, are increasingly being considered to address systemic aspects of climate-related risks, complementing microprudential measures. A growing body of policy analyses is exploring the potential role for macroprudential capital buffers, also discussing the challenges of measuring and incorporating them into regulatory frameworks. At the international level, FSB (2022) discusses the possibility of macroprudential climate capital buffers to address systemic risks arising from climate change and the transition to a low-carbon economy, pointing out that microprudential tools alone cannot sufficiently address these risks. In the UK, Bank of England has discussed the option of an "escalating" climate buffer (Bank of England, 2021) among its reflections on the optimal prudential response to climate risks. For the EU, Monnin (2021) and Hiebert & Monnin (2023) provide initial insights as to why climate risks are systemic and argue that the EU is "perfectly equipped" to address these risks using the SyRB, a macroprudential capital buffer introduced in the EU to specifically target systemic risks. The potential of the SyRB to address climate risks has also been acknowledged by various EU institutions, who have identified the SyRB as a suitable - and readily available - macroprudential tool to address systemic risks stemming from climate change (ECB-ESRB, 2022; ESRB, 2023; EBA, 2023b). Indeed, in its proposal for amending the EU banking regulatory framework, the European Commission has pointed out that the SyRB can already be used to target systemic climate-related risks (EC, 2021).

Yet, no common methodology currently exists to calibrate such buffer, which may hinder its actual use to address climate risks, should macroprudential authorities decide to use it. Such common methodology would also support a harmonized application of the SyRB in the EU, avoiding both fragmentation and migration of activities with significant climate-related risks. Our paper also contributes to the policy discussion by tackling some of the challenges which have been identified regarding the use of macroprudential tools for climate risks. In particular, ECB-ESRB (2022) identify the complex calibration as one of the hurdles to overcome in order to implement a climate SyRB. Our proposed calibration framework aims to provide a direct solution to this challenge: we propose a calibration approach using a general multi-rate SyRB based on the ECB's second top-down climate stress test. Stress test results are widely used by macroprudential authorities for the calibration of SyRBs, as they provide quantitative estimates of credit losses that would arise in banks' portfolios in a period of high financial stress (ESRB, 2017). In our application, we focus on a general SyRB applying to both banks' domestic exposures, as well as their exposures in other Member States or in third countries. By calibrating rates on granular estimates of climate-related losses, it avoids the need to rely on ad hoc classification system of sectors highly exposed to climate (transition) risk, which could have the negative side-effect of hindering credit for the transition of firms and exacerbate transition risks.[2] Using a multi-rate SyRB appears both more prudent and more efficient than a single-rate structure, because it is targeted towards the institutions most exposed to climate risks, while also providing a dynamic incentive to keep exposures below the bucket thresholds.[3]

2.2 Literature overview

Our paper is firmly situated in the nascent literature assessing the impact of climate-related risk on financial institutions and financial stability. Focusing on transition risks[4], Nguyen et al. (2023) match predicted emission footprints to the syndicated loan portfolio of the 20 largest US banks and examine losses for these banks under different climate mitigation pathways.[5] Their results reveal a strong variation in exposure to climate transition risk, with high tail-end risk. By combining industry-level estimates of the effect of carbon taxes or climate scenarios and loan-level data, Jung et al. (2023) find that US banks' exposure to transition risk is meaningful albeit relatively small and decreasing over time. Using a banking system contagion model for the euro area, Belloni et al. (2022) show that abrupt and large increases in carbon prices may lead to severe banking system losses. Using proprietary data on Dutch banks' corporate loan and residential mortgage portfolios, Reinders et al. (2023) also estimate sizable market value losses

[2]In a paper discussing the challenges in designing and implementing macroprudential policies to address climate-related financial risks, Coelho & Restoy (2023) point to the potential unintended consequences of broad-based sectoral definitions of exposures.

[3]We refer to ECB-ESRB (2023) for a discussion of the various design options for the SyRB.

[4]While our application in this paper focuses on transition risk,

[5]Martini et al. (2023) also estimate US banks' exposure to transition risk based on the carbon footprint of their syndicated loan portfolio.

following the introduction of a carbon tax, especially in scenarios of abrupt implementation. In parallel to the growing academic literature, euro area prudential authorities - as part of their increasing efforts to integrate the implications of climate change in their assessment of the stability of the financial sector - have emphasized the material exposure of euro area significant institutions to climate-related risks (Alogoskoufis et al., 2021; ECB, 2022). The most recent ECB climate stress test introduces highly granular sectoral and energy dynamics, and takes projected losses on banks' euro area corporate loans, household loans and securities portfolios into account (Emambakhsh et al., 2023). Given its comparison of different short-term transition risk scenarios, it forms the ideal starting point for our transition risk application of the climate SyRB, as discussed in more detail in Section 3. This paper directly builds on this strand of the literature, by comparing the projected losses under different scenarios, in order to isolate losses due to systemic transition risk from losses due to the broader macroeconomic environment, which is important for the calibration of the SyRB requirements.

A related strand of the literature examines the interplay between climate change policies, prudential regulation, and financial stability. Using a DSGE model, Carattini et al. (2023) find that ambitious climate policies (carbon taxes) may increase transition risk and hence financial instability, with potential negative effects on both lending to brown and green firms.[6] However, they show that macroprudential policies, modelled as taxes or subsidies on banks' assets, have the potential to alleviate this transition risk. In a similar vein, Oehmke & Opp (2022) find that a carbon tax is an effective tool to reduce carbon emissions and that higher capital requirements for loans to brown firms may help facilitate the introduction of such a tax, because they ensure that sufficient loss-absorbing capacity is available in the banking sector. Moreover, Punzi (2018) and Thomä & Gibhardt (2019) also advocate the use of such differentiated capital requirements (often called the "green supporting factor" and the "brown/dirty penalizing factor") to encourage the flow of credit to green firms and hence the transition towards a climate-neutral economy.[7] However, Oehmke & Opp (2022) argue that higher capital requirements for loans to

[6]This is in contrast to Diluiso et al. (2020), who argue that credible carbon price strategies do not necessarily endanger financial stability. However, Carattini et al. (2023) focus on an abrupt transition, while the transition in Diluiso et al. (2020) is more gradual.

[7]Similarly, earlier work by Campiglio (2016) suggests the use of green macroprudential policy in stimulating banks to finance low carbon activities.

brown firms could actually even cause a reduction in lending to green firms via a crowding-out effect. Furthermore, Dunz et al. (2021) show that a green supporting factor only contributes to increased green investments in the short-run, while it has potential negative implications for banks' financial stability. Based on an ecological macro-financial model, Dafermos & Nikolaidi (2021) confirm that green supporting factors and dirty penalizing factors may increase transition risk, through their impact on bank leverage and loan defaults, respectively. However, they argue that combining a dirty penalizing factor and green fiscal policies can be optimal from a financial stability point of view. Using an agent-based model, Lamperti et al. (2021) find that a combination of green policies, consisting of capital requirements, public guarantees and carbon-risk adjustments in credit ratings, can contribute to lower emissions without hampering financial stability. Finally, Grill et al. (2024) use a DSGE model to show the need for climate-related capital requirements by demonstrating that without specific climate prudential policies, transition risk can generate excessive risk-taking by banks. They furthermore show that imposing macroprudential policies in addition to microprudential regulation leads to a Pareto improvement. We contribute to this literature by proposing a harmonized methodological framework, based on a stress test methodology and granular supervisory data, to quantify a macroprudential capital buffer requirement to tackle climate-related risks in the euro area banking sector. In a specific application, we show that the targeted nature of the framework allows to shield the most vulnerable euro area financial institutions from a transition risk shock.

Our paper is most closely related to Alessi et al. (2022). In a first step, the authors estimate the size of bank losses due to transition risk in a non-climate-related crisis scenario, using the Systemic Model of Bank Originated Losses (see De Lisa et al. (2011)). In this model, bank-level PDs are estimated by comparing adjusted RWA, which assume that high fossil-fuel activities are 15% to 25% more risky than other assets, with actual capital levels.[8] In a second step, they identify banks which could fail due to transition risk and investigate, in a non-crisis setting, how these failures could trigger widespread fire sales in the banking sector. They propose the introduction of an additional capital buffer of (on average) 0.5% of RWA to prevent the fire sales

[8]Banks' shares of RWA towards high fossil-fuel activities are estimated by combining country-level estimates of the share of bank portfolios to high fossil-fuel activities with banks' share of corporate loans, mortgages and securities.

from happening.

In our paper, we follow a more granular approach and start from firm-level PDs (or, in the case of households, country-level PDs) in short-term transition risk scenarios, obtained from Emambakhsh et al. (2023). Using detailed loan and securities exposure data for the banks in our sample, we subsequently project bank-level losses in these scenarios. Finally, we translate projected losses into bank-specific SyRB requirements using a bucketing approach with different calibration factors.

3 Methodology

Next, we present the methodology used to determine bank-level transition risk losses and the resulting SyRB requirements. First, in Section 3.1, we provide a summarized description of the ECB top-down climate stress test (hereafter referred to as ECB CST). We use non-financial corporation (NFC) and household PDs under two scenarios from the ECB CST as main input for our calibration methodology. In Section 3.2, we explain how we translate these PDs from the ECB CST into bank-level projected losses from transition risk. Section 3.3 is dedicated to explaining in detail our climate SyRB calibration methodology.

3.1 ECB top-down climate stress test

In this paper, we present a methodological framework for the calibration of a climate SyRB, and we assess its potential application to address transition risk in the euro area banking system. PDs in the selected transition scenario and in the current policies scenario from the ECB CST form the key building blocks for this application. We provide an overview of the main aspects of the ECB CST in this section. For more details, we refer to Emambakhsh et al. (2023).

The ECB CST assesses the impact of three potential transition pathways on the euro area real economy and financial system until 2030. These evolutions are presented relative to a scenario where only minimal (and already implemented) transition efforts take place and which would thus lead to severe physical risk in the long term, the so-called current policies scenario of the Network for Greening the Financial System (NGFS). The three transition scenarios were developed by combining NGFS scenarios (NGFS, 2022) with macroeconomic forecasts from the

ECB Broad Macroeconomic Projections Exercise (BMPE)[9], and differ with regard to the timing of the transition and ambition of emission reduction over the next eight years, therefore leading to different projected temperature increases by the end of the century.[10] For the calibration of the climate SyRB in this paper, we focus on the accelerated transition scenario of the ECB CST, which assumes an immediate start of the transition that quickly brings the economy onto the optimal Net Zero 2050 pathway according to the NGFS (NGFS, 2022).[11] We select this scenario because the embedded unanticipated acceleration of the transition allows to model transition risk in the short term, between 2023 and 2025, while reducing emissions compatible with the target of reaching net zero by 2050 and taking into account recent macroeconomic and energy-related developments. Indeed, by combining climate-relevant projections of the NGFS with macroeconomic projections of the BMPE as of end-2022, the development of energy prices incorporates recent developments in the gas and oil sector and its spillover to prices of other energy sources (Figure 1, Panel A). In parallel, the main transition efforts in an accelerated transition focus on reducing the use of fossil fuels in favour of renewable energy, as well as electrifying production processes (Figure 1, Panel B). The higher demand for renewable-based electricity further drives up electricity prices in this scenario. In contrast, in the current policies scenario, the transition towards renewable energy and renewable-based electricity is substantially lower until 2030. The green transition requires investments into renewable energy and carbon mitigation activities, such as energy efficient buildings, in order to achieve the emission reduction goals. Cumulative green investments increase gradually but strongly, starting from around 0.8 Trn EUR in 2023 and amount to more than 3 Trn EUR by 2030 (Figure 1, Panel C).

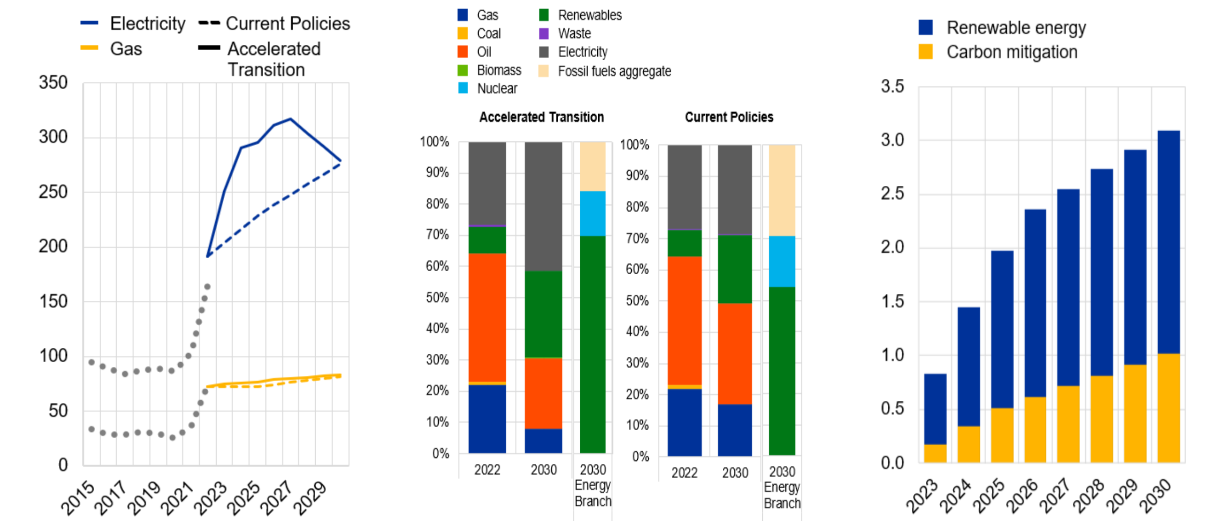
The modelling framework of the ECB CST then allows to measure the impact of transition risk on the financial risk of NFCs and households, mainly via granular risk models that respond to changes in the energy mix and green investments. For the corporate credit risk models, granular firm-level data of around 2.8 million firms in the euro area is used. Data on firms' balance sheets and insolvency status is sourced from Orbis and iBach. Firms' exposure towards

[9] Used for the 2023 EU-wide stress test (EBA, 2023a).

[10] More details on the narrative and the construction of the short-term transition risk scenarios of the ECB CST can be found in Appendix A1 of Emambakhsh et al. (2023).

[11] To properly calibrate a SyRB, it is important to select extreme but plausible climate risk realizations that identify with reasonable accuracy the key drivers of climate-related systemic risks in the real economy and how they spill over into the financial sector. For a critical review of scenario design, see Acharya et al. (2023).

Figure 1: The current policies and accelerated transition scenarios of the ECB CST (2023)



A: Historical and projected energy prices

B: Current and projected EU energy mix

C: Cumulative required green investments

Notes: Panel A: Legend of the y-axis: EUR/MWh. Panel C: Legend of y-axis: EUR trillions. No green transition investments are assumed to happen in the current policies scenario.

transition risk is measured using data on firm-level scope 1, 2 and 3 emissions (Urgentem), as well as country-sector-level data on firms' energy mix (Eurostat), which is combined to derive the energy consumption of firms by energy source. Finally, for the household credit risk models, euro area country-level data on households default frequency on residential mortgage loans (confidential supervisory data available via the COREP and FINREP reporting frameworks), real estate prices, interest rates and debt-to-income ratios (Eurostat) are used.

The ECB CST modelling framework comprises of three connected modules that separately but consistently assess risks for corporates, households and banks. In the first module, the ECB CST estimates the impact on firms' PDs due to changes in their energy expenses, energy mix, green investments, and energy demand. The main transition risk drivers are energy prices, and firms' energy mix and consumption, with the latter two being directly responsible for greenhouse gas emissions. In the short term, firms' operating costs increase due to energy price shocks, causing profits to deteriorate. Higher energy prices and climate mitigation policies provide an incentive to invest in carbon mitigation activities and renewable energy, which is mirrored by firms' increasing indebtedness. The firm-level models include sector-level amplification mechanisms in the form of downstream and upstream Gross Value Added (GVA) shocks that propagate across economic sectors in the euro area. The inter-sectoral relationships are modelled at macro level due to the (current) lack of more granular data on supply chain relationships. In a first step, economic sectors are connected via input-output GVA relationships.[12] In a second step, if the productivity of one sector is affected by the transition, resulting in a negative GVA shock, its impact is transmitted to other sectors depending on the share of input taken from / output provided to this sector. In a third step, the sector-level dynamics influence the development of firm-level financial variables, as the latter depend on sectoral GVA (among others) in a regression-based setting.[13] The resulting changes in firm profitability and leverage feed into a credit risk model that estimates transition-related PDs for corporates.

The second module assesses the impact of transition risk on households' solvency, which is driven by changes in real estate prices, long-term interest rates and households' debt-to-income ratio. Higher energy prices cause households' disposable income to deteriorate. At the same time, the green transition leads to more green investments by households aiming to reduce their energy consumption and to improve the energy efficiency of their buildings, thereby increasing households' indebtedness. The resulting changes in households' debt to-income ratio, as well as changes in real estate prices and long-term interest rates are used to project changes in the PD of households' mortgage loans.[14]

Figure 2 shows that an accelerated transition would lead to substantially higher loan-level PDs relative to a current policies scenario. PDs of the corporate sector peak in 2026, where they are 50% higher than in the current policies scenario. Afterwards, corporate PDs start to recover steadily due to recovering electricity prices and decreasing indebtedness. Household PDs are less severely affected by transition risk, increasing by less than 10% relative to the current policies scenario throughout the time frame. Similar to NFCs, the additional increase in household PDs in the transition scenario peaks around 2026 and 2027 and starts to recover afterwards.[15]

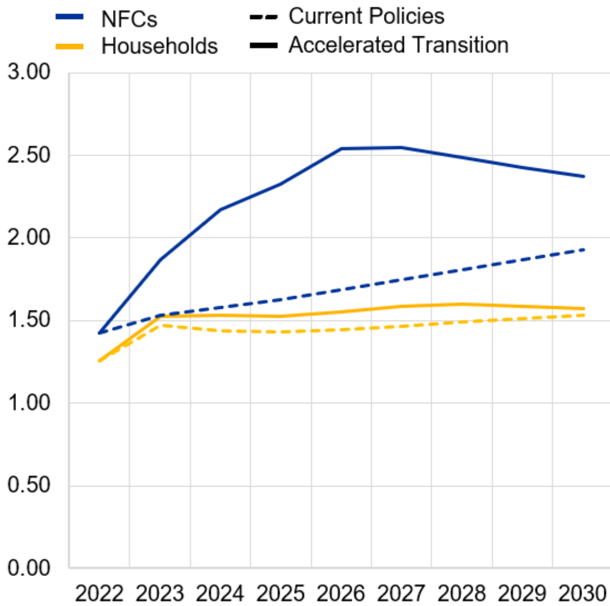
[12] Data source: Eurostat FIGARO tables. The input-output relationships are available at country-sector (NACE lev. 2) level.

[13] For example, a firm's total assets at time t depend on their value at time t-1, macro variables such as GVA and inflation, and some control variables. For more examples and the econometric specifications, we refer to Emambakhsh et al. (2023)

[14] The ECB CST uses default frequencies on residential mortgage loans (new defaulted exposures over 1 year as a percentage of total exposures), which we call 'household PDs' in the remainder of the paper.

[15] More details on the modelling methodology of the ECB CST can be found in Emambakhsh et al. (2023),

Figure 2: PDs in the accelerated transition and current policies scenario



Notes: Weighted average PDs for the loan portfolio of euro area SIs are presented. Legend of the y-axis: percentage points.

Finally, the third module of the ECB CST translates projected PDs of corporates and households into projected bank-level losses, using exposure data on banks' corporate loan, household loan and corporate debt securities portfolios. While the ECB CST focuses on a subset of euro area banks' exposures for which both climate and financial information is available at granular level, our proposed methodology also intends to capture residual exposures in order to be as comprehensive as possible. Moreover, to ensure that projected losses can be accumulated over multiple years, we will need to adapt the PDs to avoid potential double-counting of losses. Therefore, we start deviating from the ECB CST from this point onwards.

3.2 From the ECB climate stress test to transition risk losses

In this subsection, we explain how corporate and household PDs from the ECB CST are translated into projected bank-level losses due to transition risk. To obtain comprehensive estimates of transition risk losses, we project losses on banks' corporate loan, household loan, and corporate debt securities portfolios. For the purpose of this specific climate SyRB application,

Appendices A2 to A4.

we focus on the sample of euro area SIs as of end-2022 in our baseline analysis. Our sample comprises 107 SIs for which data on corporate and household loans is available. In the baseline analysis, we focus on SIs, given the more granular data coverage, as well as the higher exposure to transition risk (Emambakhsh et al., 2023). We focus on projected losses in the period 2023-2025. This medium-term horizon allows to combine the dynamics of the NGFS scenarios with the macroeconomic BMPE scenarios which are provided for a three-year time period. Moreover, this time frame is in line with existing SyRB calibration methodologies for residential real estate (ESRB, 2017).

To assess the impact of transition risk on banks' corporate loan portfolios, we first map firm-level PDs to banks' individual loan exposures to NFCs obtained from AnaCredit.[16] In a second step, since we want to cover the entire corporate loan portfolio for the calibration of the climate SyRB, we compute the residual amount of corporate credit exposures that each bank reports to each country-sector in FINREP and we use it to proxy exposures not covered in the first step. For these residual credit exposures, we use average country-sector corporate PDs.[17] To assess the impact of transition risk on banks' household loan portfolios, we use bank-level data on exposures to households resident in different countries from COREP and we map them to country-level PDs.[18] To avoid double-counting of losses over multiple years, the projected annual PDs for both corporate and household loans are multiplied by the probability that the corporate or household has not defaulted in the previous years. Subsequently, we multiply these survival-adjusted PDs with the total outstanding exposure at default (EAD, in EUR) and the loss-given-default (LGD, in per cent) of the loan to calculate annual loan losses.[19]

[16] The euro area credit register, which reports corporate loan exposures that are above 25,000 EUR. We aggregate banks' loan exposures at the level of the ultimate parent in the Single Supervisory Mechanism (SSM). More information: https://www.ecb.europa.eu/stats/money_credit_banking/anacredit/html/index.en.html

[17] The original ECB CST sample covers around 80% of euro area AnaCredit exposures. In our sample of SIs, AnaCredit exposures correspond to approximately 64% of total outstanding loan amounts in FINREP, with the remainder mainly consisting of exposures from non-euro area countries and small exposures.

[18] For household loan exposures in non-euro area countries (for which no PDs are estimated in the ECB CST), we use euro area average household PDs.

[19] More specifically, we use the following formula to calculate yearly losses on loan i:

$$Loss_{i,t} = EAD_{i,t} \times LGD_{i,t} \times PD_{i,t} \times \prod_{s=1}^{t-1}(1 - PD_{i,s})$$

Finally, for data on banks' corporate bond portfolios we use the Securities Holdings Statistics by Sector (SHSS) dataset. We map country-sector corporate PDs to corporate bond exposures in SHSS.[20] Corporate bond exposures which are not captured in SHSS are proxied using FINREP data. To calculate annual losses on the corporate debt securities portfolio, cumulative changes in PDs are transformed into changes in the bond spread, which are used to calculate price changes via the modified duration formula.[21] In line with the approach of Vermeulen et al. (2018), we assume that bond markets incorporate the losses immediately as they have the full set of information and can perfectly predict the environment of the forthcoming years. Hence, transition risk losses from the corporate bond portfolio are fully assigned to 2023, the first year in the analysis.

The combined losses in the accelerated transition scenario are an ideal starting point for the calibration of the SyRB targeting systemic transition risk, since these losses account for an unanticipated acceleration of the climate transition, which leads to a system-wide transition shock that affects all banks simultaneously, while maintaining the economy on a path compatible with net-zero emissions by 2050. However, we cannot attribute the full magnitude of the projected losses in this scenario to the transition, since the losses might also be driven by the general macroeconomic scenario which is used in the stress test. This macroeconomic component should not be taken into account in the calibration of a climate SyRB, since it is already covered in banks' provisioning or in other capital buffers (i.e., P2G). To overcome this issue, we subtract the projected losses in the current policies scenario from the projected losses in the accelerated transition scenario. Since both scenarios feature exactly the same macroeconomic shocks and only differ regarding the climate shocks, focusing on the additional losses in the accelerated transition scenario (on top of the losses in the current policies scenario) allows to isolate the losses stemming from the transition from, e.g., the losses driven by the broader macroeconomic context. Moreover, if we assume that the current policies scenario is the scenario which is expected by banks to materialize, subtracting losses in the current policies scenario from the losses in the accelerated transition scenario also allows to remove any transition-related losses for which the

[20] Available for 72 of the SIs in our sample. More information: https://data.ecb.europa.eu/data/datasets/shss/data-information.

[21] More details can be found in Emambakhsh et al. (2023), Appendix A4.

institution has potentially already provisioned.[22] Finally, we make the reasonable assumption that the resulting unexpected climate-related risks are not yet targeted by other microprudential or macroprudential capital (buffer) requirements, which is a condition that needs to be assessed carefully by macroprudential authorities before activating the SyRB, in line with Article 133 of the Capital Requirements Directive (CRD).[23]

It should be noted that the projected transition risk losses in this paper are likely to be a lower bound estimate, for at least two reasons. First, even though the application is based on a state-of-the art stress test, existing stress testing models are still unable to capture all amplification channels which would ideally be included. As an example, additional systemic mechanisms such as fire sales or correlated defaults are likely to increase projected losses. Nevertheless, the latest version of the ECB CST already incorporates promising systemic features, such as system-wide climate-related shocks, and GVA shocks propagating from one sector to another. It also allows to investigate potential amplification effects driven by a combination of a transition shock and an adverse macroeconomic scenario (cf. Section 5.1). Therefore, the ECB CST represents a very advanced starting point for a realistic application of our SyRB calibration framework. A second reason why the current projections are likely to be a lower bound estimate for climate-related losses, is that our application solely focuses on short-term transition risks, thereby abstracting from the impact of potential simultaneous realizations of physical climate-related risks, such as floods or wildfires. Hence, if this application were to be repeated using stress tests including some of those elements, the resulting projected losses will arguably be higher than what is presented in this paper. However, by proposing a calibration framework which is independent of the chosen stress testing approach, we allow macroprudential authorities to benefit from the continuous improvements in stress testing models and scenarios for their future SyRB calibration exercises.

[22]It is important to make a distinction between our proposed methodology and the specific application. While this assumption is important for the results in our application, an advantage of the methodology is that it can be flexibly applied to different scenarios, and adjusted over time as the transition unfolds. Hence, when using this framework for climate SyRB calibration, prudential authorities should make sure that the current policies scenario aligns as closely as possible with financial institutions' current expectations and provisioning behaviour.

[23]The extent to which the climate SyRB might overlap with other capital (buffer) requirements can also be used to inform macroprudential authorities' decision on the optimal calibration factor, as discussed in Section 3.3 and 4.3.

3.3 Calibrating the SyRB requirements

After isolating the unanticipated transition-related component of the projected losses (expressed as a percentage of RWA), these losses can be used to determine a bank-specific climate SyRB, also expressed as a percentage of RWA. Since according to EU law the SyRB has to be set in steps of 0.50 percentage points or multiples thereof (cf. Article 133(9) CRD), we map the continuous transition risk losses into different buckets with a 0.50 percentage points width. The bank-specific climate SyRB requirement depends on the bucket to which a financial institution is allocated, and the value of the SyRB matches the losses projected in the middle of the bucket. Given that some banks will potentially be very close to one of the thresholds, actual policy implementation might require some expert judgement or fine-tuning methodology to deal with these borderline banks.

While the bucketing approach is a pragmatic solution for the calibration of the SyRB, it also has the advantage of being simple and predictable, with a clear relation between the different buckets and the associated SyRB requirement. Moreover, the approach is aligned with the conceptual framework used for the O-SII/G-SIB buffer and the P2G calibration. The proposed bucketing methodology also provides macroprudential authorities with sufficient flexibility to tailor the framework to the particularities of each jurisdiction (EBA, 2020). As an example, in line with similar approaches to the calibration of prudential requirements, prudential authorities might decide to multiply the transition risk losses with a calibration factor (smaller than 1). In practice, this would imply scaling down the transition risk losses before mapping losses to different buckets. Such calibration factors may be justified to take into account additional considerations, including the potential of other capital (buffer) requirements to absorb part of the losses, the limitations of the stress test framework, or transition plans of financial institutions. For the sake of simplicity, our baseline results in Section 4.1 are based on a calibration factor of 1, i.e., without scaling down the projected losses. Subsequently, we present alternatives and discuss the policy trade-off linked to the choice of the calibration factor in more detail. In Figure 3, we present a schematic overview of the proposed calibration framework.

Finally, when implementing a bucketing approach, macroprudential authorities need to be mindful that such approaches have the potential to cause cliff effects. Borderline banks may try

Figure 3: Schematic overview of calibration framework

Transition risk losses (% of RWA)
= losses in accelerated transition scenario
- losses in current policies scenario

x calibration factor →

Bucket	SyRB
$< 0.25\%$	0 bps
$[0.25\%, 0.75\%[$	50 bps
$[0.75\%, 1.25\%[$	100 bps
$[1.25\%, 1.75\%[$	150 bps
$>= 1.75\%$	200 bps

to slightly adjust their activities and exposures to end up in a lower bucket, leading to an under-estimation of systemic risk, as argued by Behn et al. (2022). Such window-dressing behaviour around regulatory reporting dates is well-documented in the literature and is not only limited to bucketing approaches (Abbassi et al., 2023; Bassi et al., 2024). Hence, when implementing the framework, banks' behaviour before cut-off dates should be carefully monitored.

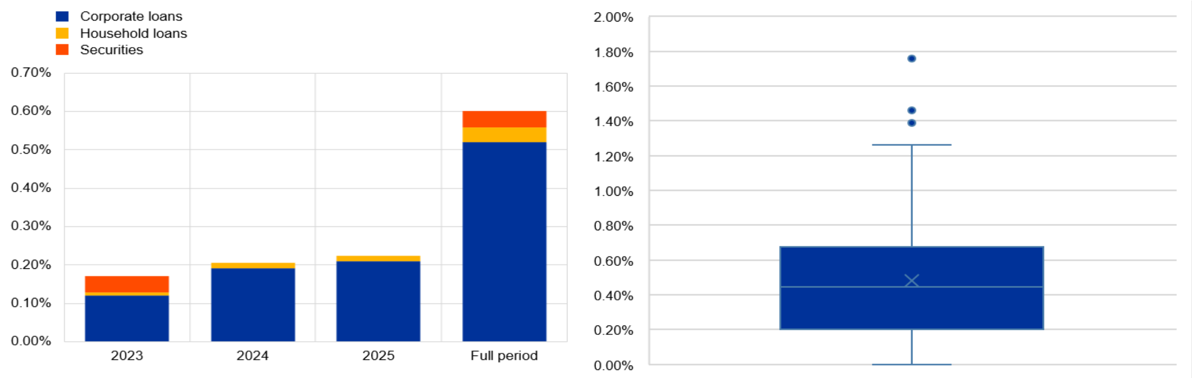
4 Results

4.1 Calibration factor of 1: absorbing all projected losses

In our first set of results, we examine losses due to transition risk over the 2023 to 2025 period, under the baseline macroeconomic scenario. We use a calibration factor of 1, which implies that the resulting SyRB will aim to absorb all projected transition risk losses. System-wide cumulative losses relative to RWA are reported in Panel A of Figure 4. Yearly losses steadily increase, reaching 0.22% of RWA in 2025. In total, aggregate transition risk losses over the full three-year period are estimated at 0.60% of RWA, or approximately 52 Bn EUR. This is sizable, representing a 31% increase relative to the current policies scenario, and it implies that total transition risk losses amount to almost 4% of aggregate CET1 capital. To note that, as discussed in detail in Section 3.2, the ECB CST does not consider fire-sale dynamics, devaluations, and second round effects. Therefore the estimated transition risk losses are likely to be on the conservative side and hence should be seen as a lower bound for policy action.

Panel A of Figure 4 also presents a breakdown of projected transition risk losses by broad balance sheet category. Losses from the corporate lending portfolio make up around 87% of aggregate losses, with the remainder being almost equally split between losses stemming from

Figure 4: Transition risk losses relative to RWA, 2023-2025



A: Aggregate losses B: Bank-specific losses

Notes: Results for euro area SIs are presented. Aggregate losses are calculated by summing transition risk losses over all SIs and dividing by total RWA. Full period losses (Panel A) and bank-specific losses (Panel B) are cumulative over the 2023 to 2025 period. Legend of the y-axes: transition risk losses as percentage of RWA.

lending to households and banks' corporate debt securities holdings. As can be seen in Figure 2, household PDs increase less than than corporate PDs in the accelerated transition scenario of the ECB CST, which explains why transition risk losses from the household loan portfolio are relatively small. This is driven by the fact that the two main drivers of the corporate PDs (profitability and leverage) are both negatively affected in the accelerated transition scenario. In contrast, the PDs on household loans also respond strongly to changes in interest rates and real estate prices, which even increase in the accelerated transition scenario, beyond the transition-induced negative impact of the higher indebtedness and lower discretionary income.[24] Finally, despite the large sensitivity of bond prices to changes in PD, transition risk losses from the corporate debt securities portfolio are rather limited due to the small size of this portfolio (compared to, e.g., corporate loans).[25] As mentioned in Section 3.2, all losses related to the corporate debt securities portfolio are assumed to materialize in the first year.

While Panel A of Figure 4 presents the aggregate picture, it should be noted that this masks substantial heterogeneity among financial institutions. Panel B of Figure 4 reveals that, while

[24] Moreover, the use of country-level data in the household model of the ECB CST implies that the impact of the transition on households is captured at a more aggregate level.

[25] While corporate loans and household loans portfolios are of rather similar size (together approximately 50% of total assets) for the average bank in the sample, corporate debt securities only account for approximately 1% of total assets.

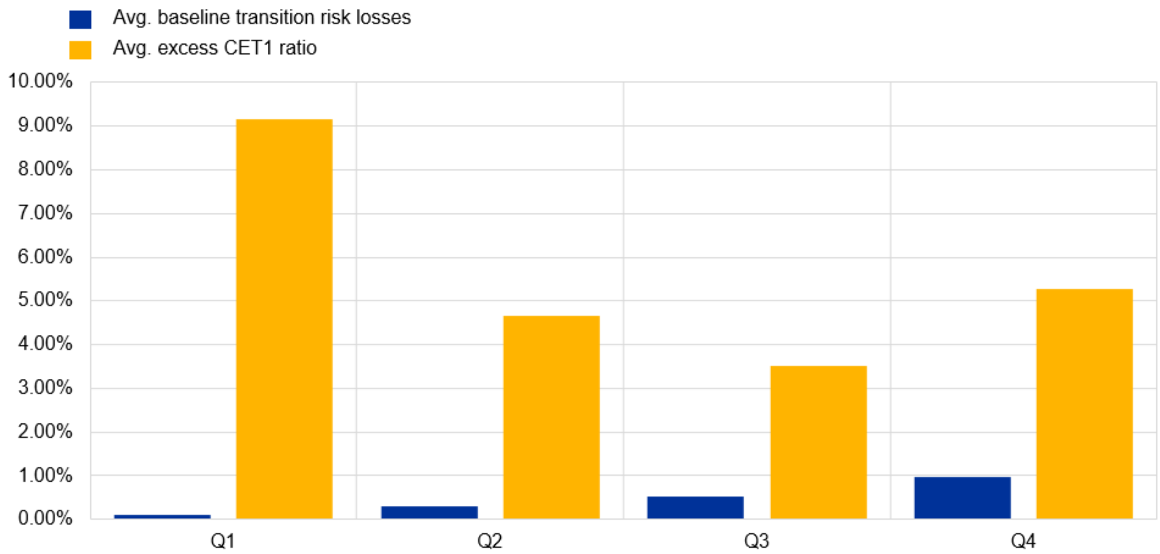
the median bank's losses are slightly below 0.50% of RWA, a handful of banks record losses well above 1% of RWA. Given that borrowers with higher emissions will have higher energy expenses, and that required investments in green technologies are proportional to the required reduction in emissions, the exposure of banks to firms with high emissions is one of the important drivers of projected losses in the model. However, it should be noted that an advantage of using this particular stress testing methodology for the calibration of a general SyRB, is that various other channels are also taken into account. As an example, the increase in energy expenses will also depend on the specific country-sector energy mix. Overall, the high degree of heterogeneity in losses is relevant from a policy point of view. It implies that a one-size-fits-all climate buffer would likely be inefficient, as it would be too low for high-risk banks while simultaneously requiring higher capital buffers for banks with low projected transition risk losses. Hence, a bucketing approach translating bank-specific projected transition risk losses into capital add-ons appears to be both more prudent and more efficient.

Next, we investigate the impact of transition risk losses on banks' capital positions and the extent to which higher transition risk losses are associated with banks with lower excess CET1 ratios (lower management buffers), which is used as a proxy for bank vulnerability. Assuming financial institutions do not hold additional provisions beyond the current policies scenario, transition risk losses will directly affect their capital positions. We define the excess CET1 ratio as the bank's CET1 ratio minus the sum of all capital and buffer requirements (including P2G). Figure 5 shows that banks with higher projected transition risk losses indeed tend to have lower excess CET1 ratios, indicating that the highest climate transition risks are present in the most vulnerable banks.[26] While excess capital exceeds transition risk losses for all banks, the potential decline in capital can be substantial, with some banks losing close to 50% of their excess CET1 capital. Approaching regulatory minimum requirements may undermine market confidence in affected banks and may worsen overall financial conditions in times of stress.

Finally, in Table 1, we show how transition risk losses are translated into climate SyRB requirements. Banks are allocated to five risk buckets based on their transition risk losses, in line with the bucketing approach described in Section 3.3. Banks with transition risk losses

[26]We exclude one financial institution with an excess CET1 ratio of more than 50%. A similar pattern can be observed when using the actual CET1 ratio as an alternative proxy for bank vulnerability.

Figure 5: Transition risk losses and excess CET1 relative to RWA



Notes: Results for euro area SIs are presented. Financial institutions are divided according to the quantiles of transition risk losses (cumulative over the 2023 to 2025 period). For each of these quantiles, average transition risk losses and average excess CET1 ratios are shown, both as percentage of RWA.

below 0.25% of RWA receive no buffer. Because their losses are fairly low, a buffer of 50 bps may be considered to be disproportionate. Accordingly, 33 banks do not receive a SyRB requirement. For the majority of banks in our sample (56), transition risk losses over the 2023 to 2025 period are estimated between 0.25% and 0.75% of RWA. These banks receive a buffer of 50 bps, striking a balance between increased resilience and proportionality. Only 18 banks receive a SyRB requirement of more than 50 bps, highlighting that the SyRB is a targeted policy intervention, with 13 banks receiving a 100 bps, 3 banks receiving a 150 bps, and another 2 banks receiving a 200 bps SyRB requirement.

Table 1: Climate SyRB

Bucket	SyRB	N. banks
$< 0.25\%$	0 bps	33
$[0.25\%, 0.75\%[$	50 bps	56
$[0.75\%, 1.25\%[$	100 bps	13
$[1.25\%, 1.75\%[$	150 bps	3
$>= 1.75\%$	200 bps	2

On aggregate, additional capital mobilized by the proposed climate SyRB amounts to 51 Bn EUR, compared to transition losses of approximately 52 Bn EUR. The SyRB is therefore able to almost fully offset the impact of a transition shock on capital positions at the system-wide level. This can be attributed to the calibration factor equal to unity, which implies that estimated losses are translated almost one-to-one into capital requirements. We discuss further alternative design options and possible trade-offs in Section 4.2 and 4.3.

4.2 Other calibration factors: partial coverage of projected losses

In the baseline application, we use a calibration factor of 1 when mapping transition risk losses to different buckets for the climate SyRB requirements. In this subsection, we discuss to what extent the use of an alternative calibration factor, i.e., scaling down the transition risk losses, affects the climate SyRB calibration.

Table 2 shows the number of banks in each of the buckets for different choices of the calibration factor (CF). In addition to the baseline (calibration factor of 1), we show the results with a calibration factor of 0.5 and 0.25, i.e we scale down losses by a factor 2 and 4, respectively.

Table 2: Climate SyRB - different calibration factors

Bucket	SyRB	N. banks CF=1	N. banks CF=0.5	N. banks CF=0.25
$< 0.25\%$	0 bps	33	65	96
$[0.25\%, 0.75\%[$	50 bps	56	40	11
$[0.75\%, 1.25\%[$	100 bps	13	2	0
$[1.25\%, 1.75\%[$	150 bps	3	0	0
$>= 1.75\%$	200 bps	2	0	0

As discussed before, in the scenario with a calibration factor of 1, the projected 52 Bn EUR was virtually fully covered by the climate SyRB of 51 Bn EUR (99%). As a result of this climate SyRB, aggregate CET1 requirements would increase by 0.59 percentage points. The lower the chosen calibration factor, the lower the number of financial institutions in the highest buckets and the lower the amount of capital to be raised in aggregate. More specifically, the amount of newly raised CET1 capital implied by the climate SyRB with calibration factor of 0.5 will only cover approximately 57% of projected transition risk losses. This would correspond to an increase in aggregate CET1 requirements of 0.34 percentage points. With a calibration factor of 0.25, the newly raised CET1 capital will cover only 3% of estimated transition risk losses at the system-wide level, because of the high number of banks with a climate SyRB of 0 bps. The aggregate increase in CET1 requirements would be a mere 0.02 percentage points.

4.3 Other calibration factors: policy trade-off

The different calibration exercises in Section 4.2 show that the choice of the calibration factor implies a policy trade-off. On the one hand, the higher the chosen calibration factor (e.g., a calibration factor of 1 in the baseline application), the more financial institutions will have to increase capital ratios to comply with the associated climate SyRB.[27] This higher capital cushion will enable banks to absorb more losses if the transition risk shock materializes, hence increasing resilience.[28] On the other hand, the literature suggests that higher capital requirements to some extent affect the growth of credit supply in the short term, which needs to weighed against the benefits for resilience that come with higher capital requirements. In other words, the higher the chosen calibration factor and the increase in resilience against climate-related risks, the higher the potential short-term adverse impact on bank lending and the real economy.[29] To shed more light on this issue, we provide a simple estimate of the potential negative impact of introducing a climate SyRB, under different calibration factors, on banks' credit supply.

For this back-of-the-envelope calculation, we rely on estimates from multiple papers assessing the impact of a 1 percentage point increase in capital requirements on banks' lending to NFCs.[30] Gropp et al. (2019) show that this leads to a reduction in credit growth by 9 percentage points for European banks, while Aiyar et al. (2014) find an effect of 5.7 to 8 percentage points for UK

[27]For this exercise, we assume that banks will increase their CET1 ratios by the full size of the newly imposed climate SyRB requirement. Put differently, we assume that banks try to keep exactly the same excess CET1 ratio (management buffer) as they had before the climate SyRB activation.

[28]In addition to increasing resilience, a multiple-rate climate SyRB could also reduce the build-up of transition risk, by providing banks with an incentive to maintain their risk exposures below the buffer thresholds, and hence benefit from the lower buffer rate.

[29]Berger et al. (2020) provide an extensive overview of the existing research on bank lending and the effects on the real economy. For the sake of brevity, we only focus on the effects of increased capital requirements on bank lending and we do not discuss the subsequent implications of this credit supply shock for, e.g., employment or investment.

[30]To facilitate comparison between the papers, we rescale all original estimates to the impact of a 1 percentage point increase in (risk-weighted) capital requirements and compound quarterly credit growth estimates over a one-year period.

banks. In contrast, De Jonghe et al. (2020) show that the effect on Belgian banks is limited to a 2.29 percentage points decline in the yearly growth of term loan credit.[31] Using US supervisory data on credit lines and term loans, Favara et al. (2021) find a reduction in loan commitments by G-SIBs of 3% to 4%.[32] Finally, recent theoretical work by Lang & Menno (2023) shows that effect of an increase in capital requirements depends heavily on the state of the macro-financial environment. While a 1 percentage points increase in capital requirements may lead to a 10% decrease in outstanding loans if banks are not able to raise sufficient equity, the reduction is only 0.1% in times when banks can satisfy higher capital requirements by retaining profits.

Table 3 provides, for each of the aforementioned papers, a summary of the effect on credit growth following the introduction of a climate SyRB with different calibration factors, based on the application presented in this paper. Based on these estimates, it is clear that the timing of the introduction of the climate SyRB and the choice of the calibration factor are important to avoid negative implications on credit growth. Given that aggregate capital requirements would increase by 0.59 percentage points (calibration factor of 1), 0.34 percentage points (calibration factor of 0.5) or 0.02 percentage points (calibration factor of 0.25), the climate SyRB requirement calibrated in this paper would lead to an estimated negative effect on credit growth of 5.94, 3.43 or 0.17 percentage points, respectively, if it were introduced in an adverse macro-financial environment. Compared to an average yearly growth in outstanding credit of close to 5% over the 2014 to 2022 period,[33] the potential reduction in credit growth is sizable, especially for the higher calibration factors. However, the negative impact on credit growth would be limited to 0.06 percentage points (calibration factor of 1), 0.03 percentage points (calibration factor of 0.5) and 0 percentage points (calibration factor of 0.25) when the climate SyRB was introduced in 'normal' (non-stressed) times. Finally, macroprudential authorities also have the flexibility to decide on the length and design of a phase-in period for the climate SyRB, in order to avoid excessive negative consequences for credit growth and take into account the current state of the broader macroeconomic environment (ESRB, 2017).

[31] Assuming banks preserve their capital buffer in response to this increase in capital requirements.

[32] The specification in Favara et al. (2021) focuses on outstanding loans rather than the change in outstanding loans, which allows to interpret their findings as a percentage change in credit instead of a percentage point change in credit growth.

[33] Based on aggregate data for the euro area, obtained from the ECB Statistical Data Warehouse.

Table 3: Potential impact of the climate SyRB on credit growth

Paper	Impact of 1 ppt increase in cap. req.	Period	Geography	Impact of SyRB with CF=1	Impact of SyRB with CF=0.5	Impact of SyRB with CF=0.25
Gropp et al. (2019)	-9 ppt	2010-2013	Europe	-5.35 ppt	-3.09 ppt	-0.15 ppt
Aiyar et al. (2014)	-5.7 to -8 ppt	1998-2007	UK	-3.39 to -4.75 ppt	-1.96 to -2.75 ppt	-0.1 to -0.14 ppt
De Jonghe et al. (2020)	-2.29 ppt	2013-2015	Belgium	-1.36 ppt	-0.79 ppt	-0.04 ppt
Favara et al. (2021)	-3 to -4 ppt	2014-2017	US	-1.78 to -2.38 ppt	-1.03 to -1.37 ppt	-0.05 to -0.07 ppt
Lang & Menno (2023)	-0.1 to -10 ppt	2005-2019	Euro area	-0.06 to -5.94 ppt	-0.03 to -3.43 ppt	-0 to -0.17 ppt

Notes: This table shows estimates for the impact on credit growth (in percentage points) of the introduction of a climate SyRB as described in the application in this paper. Estimates differ depending on the calibration factor and the original paper on which they are based. Given that the specification in Favara et al. (2021) and the model in Lang & Menno (2023) investigate the impact on outstanding loans, assuming a zero credit growth if none of the explanatory variables change, we interpret their percentage changes in outstanding loans as percentage point changes in credit growth to allow a straightforward comparison.

Besides the desired coverage of projected losses and the potential implications for credit growth, other elements may also inform policymakers' decision regarding the optimal calibration factor. As an example, macroprudential authorities' assessment of the potential overlap of the climate SyRB with other capital (buffer) requirements may be helpful in this discussion. However, detailed guidance on the calibration factor is beyond the scope of this exercise and could be addressed by additional recommendations developed by relevant authorities (e.g., the ESRB). Such recommendations would also help to ensure a harmonized calibration and implementation across jurisdictions.

5 Robustness and extensions

5.1 Adverse macroeconomic scenario

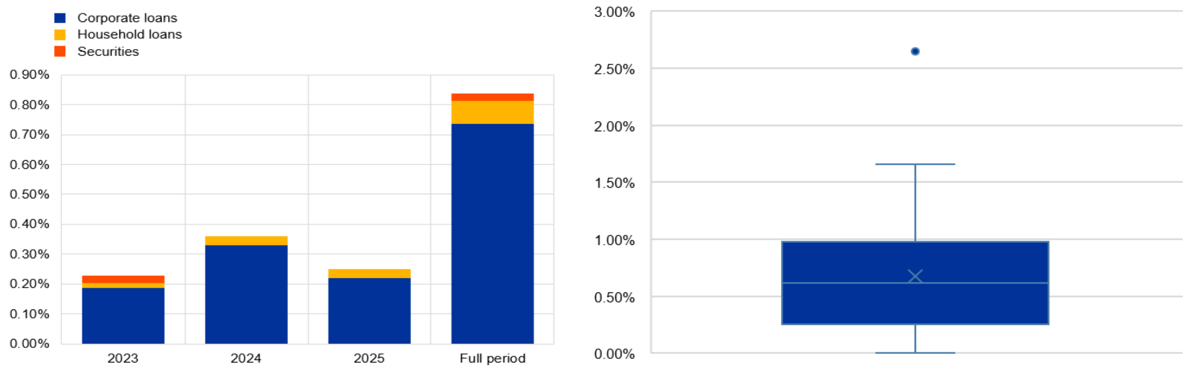
As a first robustness check, we evaluate the impact of a transition shock in a severe macroeconomic downturn. In particular, we examine the effect of the same transition shock when the economy evolves in line with the adverse macroeconomic BMPE scenario, which assumes lower GDP growth and higher gas and oil prices.[34]

Using this adverse scenario, Chart A of Figure 6 indicates that transition risk losses are substantially higher over the entire period, amplified by the adverse macroeconomic scenario. As before, we carefully isolate transition risk losses from other losses. Isolated transition risk

[34] For more details on the adverse macroeconomic scenario, we refer to EBA (2023a).

losses reach on aggregate 0.84% of RWA (72 Bn EUR) compared to 0.60% under the baseline scenario. This implies that a transition shock would have a more severe impact if the economy is already under substantial macroeconomic stress. The reason for this amplification is that, in an adverse macroeconomic environment, the gas and oil price hikes of the first three years persist rather than recover to the levels in 2022. Hence, transition risk shocks occur on top of energy price levels that are higher than in the baseline. At the individual bank level, Chart B of Figure 6 confirms this amplification of transition risk losses, with 22 banks recording projected transition risk losses higher than 1% of RWA, compared to only 11 banks in the baseline macroeconomic scenario.

Figure 6: Adverse transition risk losses relative to RWA, 2023-2025



A: Aggregate losses B: Bank-specific losses

Notes: Results for euro area SIs are presented. Aggregate losses are calculated by summing transition risk losses in the adverse macroeconomic scenario over all SIs and dividing by total RWA. Full period losses (Panel A) and bank-specific losses (Panel B) are cumulative over the 2023 to 2025 period. Legend of the y-axes: transition risk losses as percentage of RWA.

The resulting climate SyRB, assuming a calibration factor of 1, is reported in Table 4. The increase in transition losses shifts many banks from lower to higher risk buckets. While the number of banks receiving no buffer or a 50 bps buffer requirement decreases from 89 to 67, the number of banks receiving a climate SyRB of at least 100 bps, more than doubles from 18 to 40. In terms of system-wide resilience, the introduction of this climate SyRB would imply additional capital requirements of around 69 Bn EUR, compared to 51 Bn EUR in the baseline macroeconomic scenario.

Table 4: Climate SyRB - baseline versus adverse macroeconomic scenario

Bucket	SyRB	N. banks (baseline)	N. banks (adverse)
$< 0.25\%$	0 bps	33	26
$[0.25\%, 0.75\%[$	50 bps	56	41
$[0.75\%, 1.25\%[$	100 bps	13	28
$[1.25\%, 1.75\%[$	150 bps	3	10
$>= 1.75\%$	200 bps	2	2

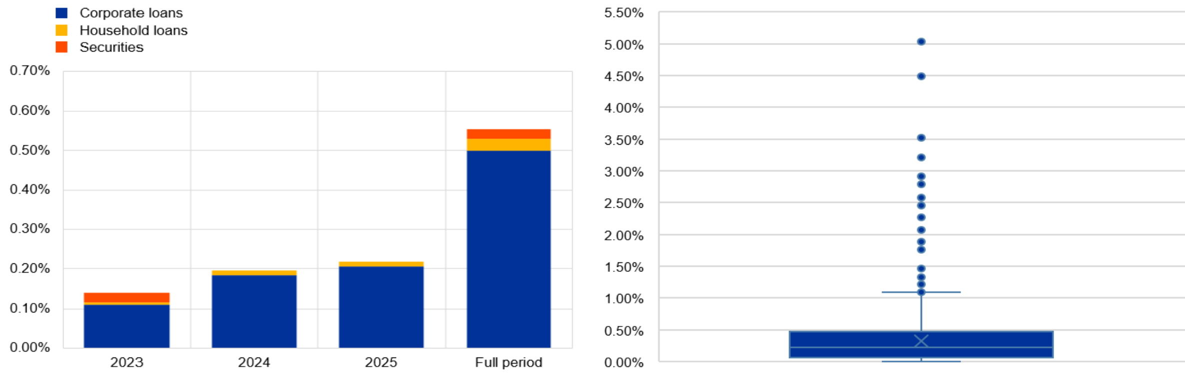
While our calibration method has the advantage to be able to easily accommodate an adverse macroeconomic environment, the ultimate scenario choice underlying any climate SyRB remains a policy decision which should be carefully considered by macroprudential authorities. Losses under the adverse macroeconomic scenario are substantially higher than under the baseline scenario, yet this scenario represents a tail event, combining two severe and relatively unlikely events. Depending on how likely macroprudential authorities deem the scenario of an unanticipated accelerated transition shock combined with a deep economic downturn, the additional capital buffer may provide a relatively low expected marginal increase in financial resilience compared to its costs and the likelihood of the shocks.

5.2 Extension to Less-Significant Institutions

So far we have presented results using the sample of euro area SIs. In this subsection, we extend our analysis and also include smaller banks, i.e., Less-Significant Institutions (LSIs). It should be noted that this extension comes with some caveats. First, for these LSIs, we have no available data on transition risk losses from the corporate debt securities portfolio. Second, as before, we proxy corporate loans which are not covered in AnaCredit using FINREP data. However, because of data limitations, we can only rely on sector proxies instead of country-sector proxies for LSIs, which makes the analysis somewhat less granular. Third, we can only include LSIs for which these FINREP data are available, which limits the sample to 1,457 LSIs (in addition to the 107 SIs from the main analysis).

The projected transition risk losses for this extended sample of credit institutions can be found in Figure 7. In Panel A, we show that aggregate transition risk losses amount to 0.55% of total RWA (or approximately 83 Bn EUR), which is slightly lower than for the sample with only SIs (0.60%, cf. Section 4.1), indicating that smaller institutions are, on average, less exposed to transition risk. Panel B confirms this picture, with transition risk losses for the median bank being 0.23% only. However, this boxplot also shows that the dispersion of bank-specific transition risk losses is much higher than in the baseline sample, with projected losses exceeding 1% for almost 50 banks and even going up to 5% of RWA for one bank. These findings strengthen the case for a targeted bucket-based calibration instead of a one-size-fits-all solution.

Figure 7: SI and LSI transition risk losses relative to RWA, 2023-2025



A: Aggregate losses B: Bank-specific losses

Notes: Results for euro area SIs and LSIs are presented. Aggregate losses are calculated by summing transition risk losses over all SIs and LSIs and dividing by total RWA. Full period losses (Panel A) and bank-specific losses (Panel B) are cumulative over the 2023 to 2025 period. Legend of the y-axes: transition risk losses as percentage of RWA.

In Table 5, we show how transition risk losses translate into SyRB rates for this extended sample of credit institutions. The low transition risk losses for the majority of banks imply that almost all banks receive a rather low SyRB requirement, with 1451 of them having a requirement of 0 or 50 bps. However, 113 banks would have a requirement of more than 100 bps, with 17 banks in the highest bucket of 200 bps. At a system level, the SyRB for climate-related risks would create an additional capital buffer of 79 Bn EUR for the combined sample of SIs and LSIs, of which 51 Bn EUR is coming from SIs (cf. Section 4.1).

Table 5: Climate SyRB - SIs and LSIs

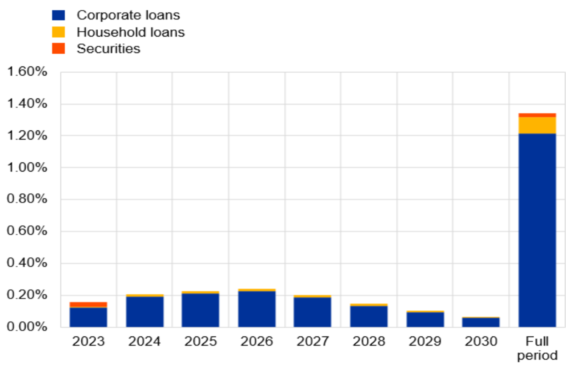
Bucket	SyRB	N. banks
$< 0.25\%$	0 bps	822
$[0.25\%, 0.75\%[$	50 bps	629
$[0.75\%, 1.25\%[$	100 bps	85
$[1.25\%, 1.75\%[$	150 bps	11
$>= 1.75\%$	200 bps	17

5.3 Longer time frame

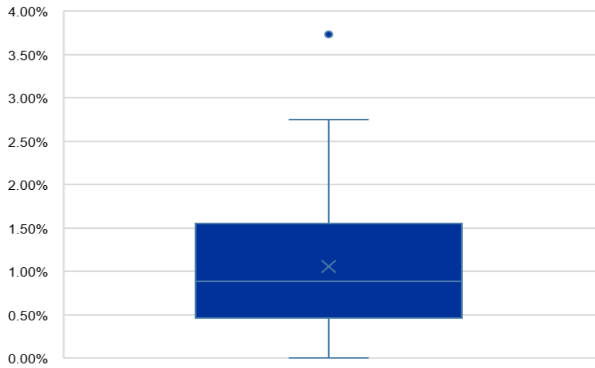
In Section 3.2, we explained that the main analysis focuses on a three-year time frame, which is in line with other buffer calibration methodologies and which allows to use the scenarios of the latest ECB-wide stress test for the calibration of the macroeconomic variables over the 2023-2025 period. Nevertheless, we want to ensure that the (relative) assignment of banks to different buckets is not driven by this specific period choice. Therefore, in this subsection, we estimate transition risk losses over the 2023-2030 period, as in Emambakhsh et al. (2023), and show that this different choice of time frame implies no meaningful changes in terms of ranking of financial institutions based on transition risk losses. For the 2023-2025 period, we use a combination of the ECB-wide stress test macroeconomic (baseline) scenario and the NGFS scenarios. For the 2026-2030 period, for which no dedicated ECB macroeconomic scenarios are available, we apply the NGFS scenarios to the end-2025 macroeconomic variables. In line with the baseline analysis, we again restrict our focus to SIs.

Chart A of Figure 8 shows the evolution of aggregate transition risk losses over time. Yearly transition risk losses increase steadily until 2026. Afterwards, projected losses start to decrease because PDs start to recover from transition risk (see Figure 2). Over the full 2023 to 2030 period, aggregate transition risk losses amount to 1.34% of RWA or 115 Bn EUR. Chart B of Figure 8 shows that the median bank has projected transition risk losses of 0.89% of RWA. Again considerable dispersion exists among the banks in the sample, with maximum losses above 3.50% of RWA for the most severely affected bank. These findings confirm that the relative ranking of banks, and hence their corresponding SyRB rate, is not driven by the choice of a specific time horizon and is robust to the use of an alternative time frame. Indeed, as shown in Figure 9, banks with high projected transition risk losses over the 2023-2025 period also have high projected losses over the 2023-2030 period. The Pearson correlation between both series is 0.93, while the Spearman (rank) correlation is 0.95.

Figure 8: Transition risk losses relative to RWA, 2023-2030



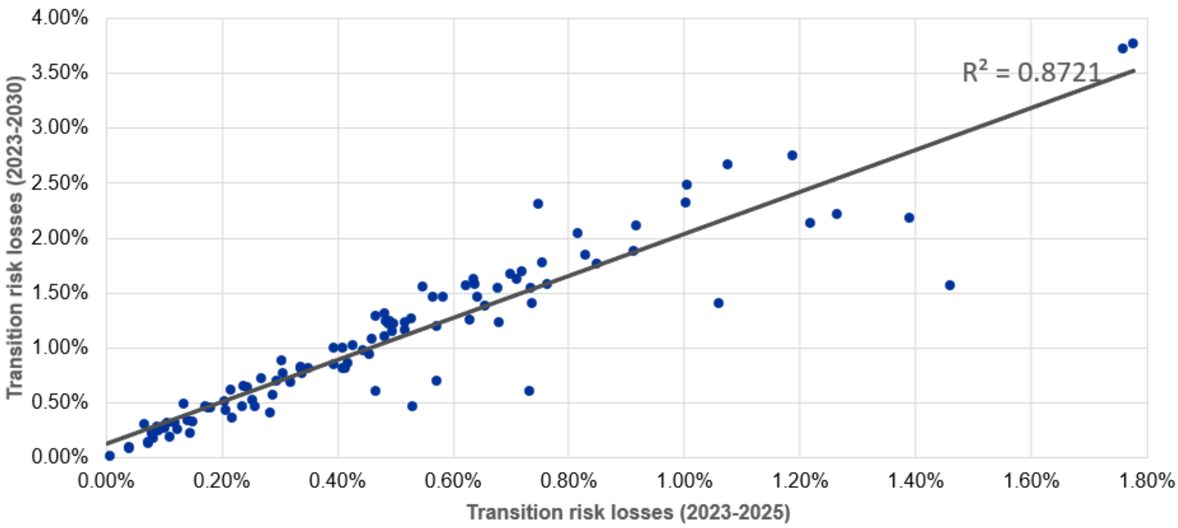
A: Aggregate losses



B: Bank-specific losses

Notes: Results for euro area SIs are presented. Aggregate losses are calculated by summing transition risk losses over all SIs and dividing by total RWA. Full period losses (Panel A) and bank-specific losses (Panel B) are cumulative over the 2023 to 2030 period. Legend of the y-axes: transition risk losses as percentage of RWA.

Figure 9: Comparison of transition risk losses across time periods



Notes: Results for euro area SIs are presented. Legend of the x-axis: cumulative transition risk losses over the 2023-2025 period, as percentage of RWA. Legend of the y-axis: cumulative transition risk losses over the 2023-2030 period, as percentage of RWA.

6 Conclusion

This paper contributes to the academic literature and the policy debate on the prudential response to climate-related risks by providing a novel assessment of the impact of these risks on the euro area banking sector and demonstrating the potential of macroprudential capital buffers to mitigate potential climate-related losses at the system level. We propose a harmonized calibration methodology based on a state-of-the art climate stress test approach, which allows to address the largely forward-looking nature of climate risks and to calibrate the prudential response based on a severe, but realistic, scenario where systemic climate risks materialize. The estimated losses are then used to calibrate a SyRB so as to offset the system-wide losses attributed to the climate transition stress. While translating transition risk losses one-to-one into different buckets would fully offset the estimated aggregate losses, we show that the use of alternative calibration approaches allows to fine-tune the additional capital requirements to take into account policy trade-offs and mitigating factors. Robustness checks confirm that the proposed methodology delivers comparable outputs when changing the sample and time horizon. Overall, the paper represents an important step towards the utilization of macroprudential capital buffers for climate-related risks. The proposed methodology provides a general reference framework for the calibration of such buffers that can be flexibly adjusted depending on the specific circumstances (e.g., using stress test scenarios capturing also the physical dimension of climate risk) and which is available for implementation should macroprudential authorities decide to do so.

Future research and policy work could build on and refine our contribution along the following dimensions. First, the choice of the relevant climate scenario under which bank losses are to be assessed is a key decision and a primary diver of the results of the calibration. The scenario used for calibration of a macroprudential capital buffer like the SyRB will need to be chosen carefully to correctly identify realistic sources of systemic risk, including the potential interaction between transition risk and physical risk. Furthermore, given the uncertainties surrounding climate risks, it will be crucial to evaluate multiple scenarios and have a sound methodology for the selection of the appropriate scenario to calibrate the buffer, robust to our evolving understanding of climate risks. Advances in short-term climate scenarios will be important in informing these decisions (NGFS, 2023). Second, future work could aim to capture additional systemic amplifiers. Expanding the climate stress test methodology to better account for other channels that amplify and propagate the effects of climate shocks (e.g., contagion effects or fire sales) would be particularly beneficial. Third, in our proposed calibration framework, we implicitly assume that the need for activation of the climate SyRB requirement has already been identified. In practice, however, macroprudential authorities would need to assess whether or not the activation of the macroprudential tool and the accompanying stress test exercise are warranted in the first place, requiring appropriate methodologies to inform their decision. Fourth, concrete implementation would need to ensure that macroprudential capital buffers are not targeting climate-related risks already covered by other microprudential or macroprudential capital (buffer) requirements, to avoid any overlap of requirements and double-counting of risks. Finally, future integration of firm-level transition trajectories in the definition of transition risk exposures, e.g., by incorporating information from transition planning, could enhance the efficiency of a capital buffer for climate risks, further reducing the risk of negative side effects on transition finance (Coelho & Restoy, 2023).

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