

The macroprudential challenge of climate change

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by
ECB/ESRB Project Team
on climate risk monitoring



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Executive summary

As work on laying the analytical foundations for measuring climate-related financial risk matures, there is a need to better gauge its implications for systemic risk, and associated scope for a macroprudential policy response. Previous assessments of climate-related risks to financial stability for the European Union have highlighted granularity and heterogeneity of the impacts stemming from both adverse physical shocks and transition dynamics.¹ Beyond the related concentration risk, they have also demonstrated strong path dependence in climate-related risk, whereby any costs of timely upfront action are more than offset by future risk benefits in terms of reduction. At the same time, a maturing body of work has also highlighted analytical gaps relevant for systemic risk, notably in terms of *scope* (interaction with financial vulnerability and economic feedback), *scale* (interconnectedness and contagion between financial sectors) and *horizon* (how long dated shocks could translate into short-term financial stress, alongside a more in-depth modelling of dynamic behaviours). Notwithstanding these gaps, a growing body of empirical evidence on climate-related risks to financial stability has now provided a robust analytical foundation for macroprudential policy considerations, spanning both the cross-sectional and time series dimensions of systemic risk.

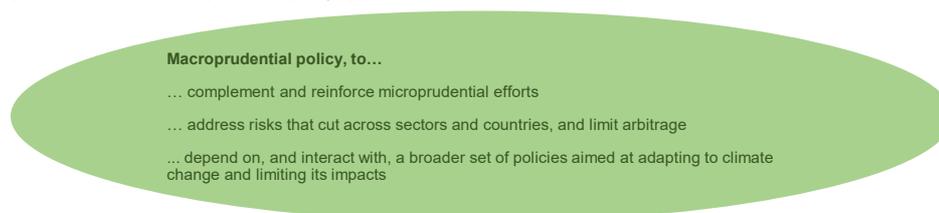
Figure 1

Overview of report contents

Build on a growing body of empirical evidence, addressing analytical gaps (*scope, scale and horizon* of climate risk)...



...to support reflection on macroprudential policy options



Work on linking climate vulnerability to standard financial risk measurement has intensified, while the understanding of the interdependencies and spillovers that could aggravate

¹ The Advisory Technical Committee/Financial Stability Committee Project Team on climate risk has been active since 2019, tasked with improving the quantitative basis for evaluating the nexus of climate change and financial stability. See ECB/ESRB Project Team on climate risk monitoring (2021), "Climate-related risk and financial stability", July and ECB/ESRB (2020), "Positively green: Measuring climate change risks to financial stability", June.



systemic risk has also deepened. Work on the measurement of climate-related financial risk has focused on two specific areas:

- A first measurement focus has been to consolidate and refine climate exposure mapping, and to link such climate exposures to standard measures of financial risk more effectively. These measures suggest that no meaningful reduction in emission intensity in the loan portfolios of euro area banks has taken place in recent years, despite the falling carbon intensity of firms. The transition-risk exposures of euro area banks remain particularly pronounced in a few climate-relevant sectors, with the loan-weighted emission intensity of exposure to the mining, manufacturing and electricity sectors still representing around 60% of the total. At the same time, a combination of climate-related and more traditional financial vulnerabilities might leave a broader set of economic sectors (including agriculture, construction and transport) at particular risk. Exposures to climate-related losses also remain concentrated at the level of banks, with more than 20% of potential losses residing in the holdings of 5% of euro area banks. There is, of course, the possibility that banks' risk management has been reinforced with respect to the prevailing corporate exposures, as awareness of climate risks grows. In this respect, some adjustment appears to be taking place in the financed activities of the broader EU financial sector, with a small decrease in financing of activities more heavily exposed to transition risk within highly climate-sensitive sectors (e.g. mining and quarrying), amid increasing transparency in disclosures. Beyond corporate lending, where the data is most complete, country-level indications suggest that risk also exists for household lending, with almost half of outstanding mortgages to borrowers with stretched energy- cost-to-income levels, most notably in rural areas.
- A second measurement focus has been gauging the prospect of systemic amplifiers. In particular, credit risk materialisation during a green transition might cluster. This might not only affect high emitters through transition risk; exposures to firms that were previously only weakly correlated could also be affected. A disorderly sharp rise in carbon prices might result not only in a five-fold increase in banks' risk-weighted-assets below regulatory thresholds through direct production linkages, but also in a near-doubling of the average default correlation of a broader set of firms through counterparty risk channels. This suggests limited scope for hedging via diversification. The same issue also applies to physical risk, where climate hazards are not independent, and can also cluster. This could aggravate fire sale dynamics due to overlapping portfolios in the case of an abrupt reassessment of climate risk pricing resulting, for example, from a salient physical risk event or a surprise transition risk shock. Common exposures across banks and nonbanks could lead to such a "hot potato" effect with associated asset price contagion. Overlapping investments between institutional sectors are heavily exposed to wildfire risk (45%) and heat and water stress (around 30%). Simulations show that a gradual greening of bank balance sheets, particularly among the most exposed banks, could eliminate the vast majority of transition risk losses.

Work has continued to sharpen a forward-looking dynamic view of the modelling of financial stability risks stemming from climate change, noting that the past is unlikely to be a good guide. The report deepens the understanding of three important dimensions of scenario analysis.

- First, the long-term *horizons* associated with climate change scenarios, while important to frame the tradeoffs between transition and physical risk, might underplay the prospect of



short-term abrupt climate-related shocks more aligned with the traditional stress testing horizon. Long- and short-term scenarios alike suggest that sharp adjustments at the level of economic sectors will underpin any aggregate impacts, affecting both the credit and the market risk of banks due not only to exposure to affected firms (for which granular financial data are most abundant), but also to exposure to households and governments. While an orderly transition would boost EU economic output by 3% compared with current policies by 2050, this might mask major shifts at the level of economic sectors, with losses in the range of 40% for fossil fuel producers in the case of a delayed transition. Nearer-term scenarios show –as would be expected– that the initial short-term costs of transition could exceed the initial benefits of reducing physical risks, which accrue with time absent climate tipping points.

- Second, the issue of *uncertainty* in accurately modelling novel aspects of financial sensitivity to climate-related risk is tackled. Forward-looking estimates of climate impacts through the prism of models can involve strong assumptions, or climate proxies. In order to gauge the uncertainty surrounding such assessments in practical terms, the report includes a horse race of existing models within ESRB/Eurosystem membership – building on modelling developments to date – and discusses how results vary according to the various modelling choices and assumptions. Across approaches, the results suggest that climate shocks are initially manifested in revised market expectations, affecting equity prices first, before trickling into corporate bonds. With time, market risk is accompanied by credit risk. This sequence of risk materialisation combined with balance sheet structure implies a more immediate hit to investment funds and insurers, than to banks – although with the passage of time, all parts of the financial system are touched by climate-related risk. The market losses of insurers could potentially amount to 3% of stress-tested assets, and those of investment funds to 25%, in an adverse transition. Ultimately, regarding the credit risk of banks, corporate defaults would be around 13-20% lower in 2050 in an orderly transition, compared with current policies. The persistence of associated sectoral impacts differs according to the approach adopted, highlighting the importance of modelling uncertainty. Transmission channels are also laid out for the household and sovereign sectors, though the empirics remain more limited and less comprehensive granular information does not allow as detailed a set of empirical takeaways as for firms.
- Third, the issue of *dynamics* is tackled. As noted above, insurers and investment funds benefit from the green transition immediately, experiencing a sharp reduction in market risk losses due to the favourable revaluation of their asset holdings. However, delaying and compressing the green transition sharply reduces the relative medium-term gains of banks, insurers and investment funds. Ultimately, with an unusually long horizon, the prospect of reactions to an evolving climate landscape requires consideration, both by financial institutions, which may seek to manage these risks by adjusting their exposure, and by the affected counterparties. The report provides a high-level summary of the methodological approaches that could be considered for dynamic balance sheet modelling for the banking, insurance and asset management sectors, while also estimating the amplification risks deriving from the interactions of these sectors. Risk propagation within the financial system appears to be most relevant for banks. That said, second-round effects are particularly striking in the case of market risk: the system-wide amplification of initial market risk shocks in an orderly transition result in revaluation losses over four times lower than under current policies.



As evidence accumulates on the systemic dimension of climate-related financial risk, so too does the case for a macroprudential response. A broad collective policy response would forcefully address the unprecedented, path dependent and widespread impacts of climate change. It would preferably include a carbon framework and industrial policy designed to directly tackle any allocative market failures, as well as informational market failures. Such policies could limit losses due to climate-related financial risk, while also reaping the benefits of a timely transition. The contribution of the prudential realm would stem from its mandate, namely a risk-based focus for the financial system, ensuring complementarities cutting across a micro- and macro-response. While the former covers the specific risk of individual institutions, the latter should address the externalities associated both with a *risk build-up* phase (the financing of projects that are inconsistent with a net zero transition, hence contributing to higher physical and/or transition risks at the level of the economy), and with a *corrective* phase (additional interconnectedness that climate-related financial risk brings to the financial system, with an increased risk of second-round effects).

The report discusses the options for delivering a coordinated European macroprudential response, and considers a range of possible instruments that could be used in this respect. Currently, no macroprudential instrument appears readily available and fit for purpose without some adaptation. However, some could be implemented with only limited adjustments and others would be straightforward to develop. An inventorying of available macroprudential instruments in the banking sector suggests that adapting and developing measures to limit concentration could help address systemic risks across the board, notably by addressing risks that cut across sectors and limiting arbitrage. The time dimension of systemic risk is more challenging and may require more novel adaptations of the existing macroprudential toolkit. More generally, any macroprudential action to address risk would benefit from an improvement in the quantity and quality of (forward-looking) disclosures. As forward-looking commitments proliferate, there is a possibility not only that decarbonising will follow, but also that increased disclosures will bring more transparency and influence market pricing. In practice, however, the threat of greenwashing might inhibit efficient market pricing, implying an adverse selection premium for all firms. Lastly, strong international coordination, beyond Europe's borders, is essential, given that there are clear spillovers and interdependencies between global jurisdictions.

As work to quantify the financial stability aspect of climate-related risk matures, the mainstreaming of climate metrics into ongoing financial stability surveillance is needed, in order to support concrete macroprudential policy discussions. Founded in early 2019, this Project Team on climate risk monitoring was tasked with improving the quantitative basis for evaluating the nexus of climate change and financial stability. In recent years, the team has leveraged the analytical capacity of its members to further the conceptual and empirical understanding of the systemic dimension of climate-related financial risk, complementing other initiatives in the evolving debate in the public and private sector. Its focus in future will shift to corralling a growing body of analysis into permanent financial stability surveillance, to support more concrete macroprudential policy discussions at the European Union level.



1 Introduction

This report documents progress in the measurement and modelling of climate-related risks to EU financial stability. Accurate measurement is essential for the monitoring of evolving climate-related risk to financial stability. This includes tracking an evolving disclosures landscape, while also translating climate-related disclosures into more familiar metrics of financial risk which could support prudential policy. Such financial risk, in turn, may be amplified through contagion and interconnectedness, whereby pockets of vulnerability spill over into financial system-wide risk. Moreover, modelling the forward-looking attributes of climate change is necessary to gain an accurate view of its evolution, taking the limitations of the past into consideration. The report details how climate change is not only a long-term phenomenon and could feasibly generate short term stress for firms, households and also governments. These elements raise the prospect of losses at individual financial institutions which are not additive but rather affect the whole financial system in the case of common exposures and correlated defaults. The above findings build on previous findings that have identified both pronounced concentrations in financial exposures to climate change and strong path dependence in the evolution of financial risk.²

The report also builds on empirical findings to date to provide the conceptual foundations of a macroprudential policy response. The expected broad economic and financial impacts of climate change, combined with the possibility of numerous market failures, justifies a general role for public policy. The specifics of this response, however, requires careful examination to incorporate the strengths of individual policy levers. On the prudential side, the safety and soundness of financial institutions in the face of climate-related financial risk, as well as any threats to broader financial stability, require a well calibrated response. Within the mix, macroprudential policy could counter potentially contagious risk concentrations across the financial system, along with risk build-up resulting from the interplay of the financial system with the macroeconomy.

The remainder of this report is organised as follows. Section 2 outlines a growing set of financial stability relevant indicators of climate-related risk relevant to financial stability. Section 3 details the progress made in modelling the forward-looking attributes of climate change. Section 4 presents the case for macroprudential policy and how a growing body of evidence can underpin a macroprudential response to associated risk. Section 5 concludes.

² See ECB/ESRB Project Team on climate risk monitoring (2021), "**Climate-related risk and financial stability**", July, and ECB/ESRB (2020), "**Positively green: Measuring climate change risks to financial stability**", June.

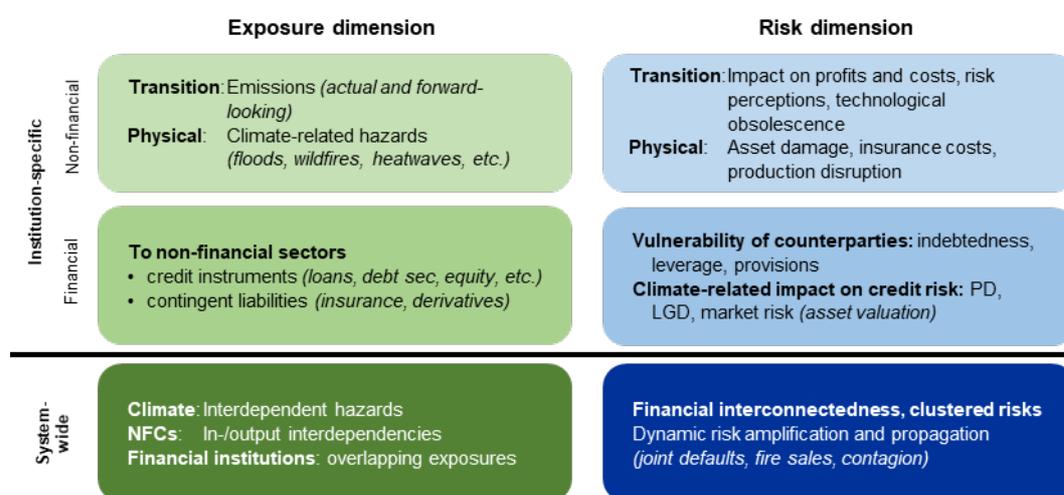


2 Data and measurement

2.1 Measuring climate-related risks to financial stability

Monitoring climate-related risks to financial stability requires the quantification of climate-related factors, their impact on economic activities and risks to the financial system. This section leverages previous work³ on the assessment of exposures to transition and physical risk, in order to develop metrics that capture the nexus between climate and financial stability risk. As a first step, it enhances the risk measurement of individual financial and non-financial institutions, using a range of datasets available to the member institutions of the Project Team. As a second step, it incorporates the systemic dimension of risks that integrate interactions among climate-related hazards as well as economic and financial institutions, in order to capture the risks for the financial system as a whole. For the systemic dimension, a range of models is activated with simulation techniques. In order to structure the various components, this section proposes a monitoring framework for climate risk.

Figure 2
Climate-related exposure-risk framework



The development of a financial stability monitoring framework requires relevant vulnerability metrics, building on previous climate exposure mapping. Non-financial borrowers are exposed to climate-related factors such as greenhouse gas (GHG) emissions or physical hazards, and financial institutions are exposed to non-financial entities mainly through credit instruments and insurance liabilities (top rows of Figure 2). The risk dimension can be quantified through the impact

³ See ECB/ESRB Project Team on climate risk monitoring (2021), "**Climate-related risk and financial stability**", July, and ECB/ESRB (2020), "**Positively green: Measuring climate change risks to financial stability**", June.



of climate-related factors on the incomes, profits, costs or damages of non-financial borrowers, and on credit or valuation risks for financial institutions. The risk assessments for financial firms require detailed knowledge about the impact of climate-related factors on financial risks (probability of default, loss given default or market valuation). Given that there is a lack of historical data, the information necessary to quantify such risks can be proxied by the existing vulnerabilities of non-financial borrowers (vulnerability metrics).⁴

A financial stability monitoring framework also needs to capture system-wide risks, notably those arising from interdependencies and spillovers. Indeed, the exposures and riskiness of individual institutions may be subject to interdependencies between climate-related factors, economic entities and financial institutions. Such system-wide aspects give rise to the amplification and propagation of risks to financial stability (bottom row in Figure 2). For example, input-output interdependencies of economic activity are a source of risk propagation within the real economy. Such real economy propagation may be further amplified by financial linkages through overlapping exposures of financial institutions as well as feedback loops between the real economy and the financial sector. Taken together, these system-wide factors can give rise to clustered risk materialisation and contagion.

Based on the available framework, the section reveals several new findings. Banking sector loan-weighted emissions of non-financial corporates have registered a limited decline since 2015, amid lower sectoral emissions accompanied by portfolio shifts to less emitting sectors. These exposures have remained strongly heterogeneous across countries. In turn, banking exposures to household loans are tilted towards higher emission-to-income households, indicating a possible transition risk. Financial market metrics capture the forward-looking component of risk but are strongly conditional on climate risk scenarios, highlighting the importance of using multiple scenarios. As regards the system-wide dimension, transition risk as a common risk factor can alter the correlation structure of credit risk and reduce the possibility of diversification within the financial system. Similarly, interdependent physical hazards may create clustered risks across geographies and time. Such interdependencies, together with economic and financial networks, can amplify risks and need to be considered for prudential regulation and policy purposes. Finally, to hedge transition risks, some financial innovations have been introduced, based in part on emission allowances, which would benefit from additional market-based alternatives. Physical risk mitigation through loan collateralisation appears to be an important factor in the mitigation of banking sector losses, but the value of collateral assets themselves could be impaired by climate-related events, calling for a strengthening of insurance options and physical resilience measures, given the risk of a growing protection gap.

Ongoing European and global initiatives should help to close the data gaps that remain in climate reporting. In the corporate sector, climate-related disclosures have improved and are expected to increase further in the coming years thanks to a range of international initiatives such as the EU's proposed Corporate Sustainability Reporting Directive (CSRD) and the International Sustainability Standards Board (ISSB) established by the IFRS Foundation to enhance disclosure requirements. Exposure metrics need to capture the transitional nature of climate-related risks, which will entail significant improvements in the consistency, granularity and reliability of forward-

⁴ Section 3 provides methodologies and estimates for credit risk parameters based on specific climate-related scenarios in a stress testing context.



looking information disclosed by firms such as emission reduction targets and net zero commitments. While the corporate sector has been a natural focus of climate risk reporting and monitoring to date, granular reporting for other non-financial sectors – encompassing sovereign and household exposures, as well as the external sector – is key to developing a more comprehensive understanding of the extent of climate-related financial risk. This reporting would have to be verified through auditing mechanisms to be sufficiently reliable.

Table 1
Overview of exposure and risk metrics with remaining gaps

Climate-related exposures, risks and gaps					
	Exposures	Financial risks and Vulnerabilities	Systemic risk	Remaining gaps	
Non-financial	Households	Emissions per m2	Emission-to-income	Spillovers through aggregate demand (income, unemployment)	- Granular household data - Energy performance certificates
	NFCs	GHG, CO2e emissions (intensity) Physical hazard exposures	Emission-to-allowance gap (EU ETS) Sensitivity to carbon tax	Energy- input/output interdependencies	- Increased, audited and forward-looking granular disclosures
	Sovereign		Sovereign climate risk sensitivity	Solvency as re-insurer of last resort?	- Loss attribution insurance- sovereign transition path (tax revenue, investment and subsidies)
Financial	Banks	Emissions and physical hazards: - Credit-weighted exposures - Loan carbon intensity (efficiency) - Overlapping/concentrated exposures	- Vulnerability-weighted exposures (Transition/physical risk-to-credit-intensity) - Climate risk sensitivity - Transition vulnerability factors	- Correlation of physical hazards - Carbon-induced default and price contagion	Loan/security risk integration
	Non-banks (Funds, ICPFs)	- Credit-weighted exposures - Loan carbon intensity - Indirect exposures of banks, insurance companies and investment funds - Overlapping exposures (emissions and physical hazards)	- Vulnerability-weighted exposures - Portfolio repricing risk (carbon price/ physical risk)	- Contagion via risk reassessment - Financial markets: asset pricing, CRISK, climate VaR, climate return shortfall, transition path rating	- Cross-sector risk integration - Granular insurance coverage

Sources: Transition risk (emissions) data: Eurostat, Urgentem, Refinitiv, European Union Registry, Physical risk (climate hazards) data: Moody's Four Twenty Seven, EC-JRC Risk Data Hub.

Analytical gaps are also an issue from a systemic risk standpoint –notably related to the independencies of financial institutions in the attribution of losses. In particular, the role of collateral and insurance in distributing losses within the financial system remains an area for major development and would augur for the integration of granular databases across institutions. A key factor for the assessment relates to the insurance protection gap for physical risks, as it could spill over into sovereigns if risks materialise. At the level of the financial markets, recent growth in ESG-related financing products has further strengthened transition financing options. At the same time, instruments for hedging and diversifying climate-related risks in Europe remain scarce.



The remainder of this section covers an array of quantitative findings linking climate-related factors to financial stability risks. Within the monitoring framework, the work covers exposures of firms and households to climate-related factors and the financial exposures of financial sectors (Section 2.2). The proposed quantitative tools include risk and vulnerability metrics for individual financial institutions (Sections 2.3) as well as for the system as a whole (Section 2.4). These metrics will enhance the monitoring of financial stability risks and provide policymakers with evidence for the development of regulatory and supervisory responses to climate-related risks.

2.2 Climate-related exposure, risk and vulnerability metrics

2.2.1 Exposure metrics

A foundational building block of a climate-related risk framework is the identification of exposures. Ideally, a full range of metrics should cover the GHG or CO₂ equivalent emissions of non-financial sectors (firms, households and sovereigns), and relate them to financial institution exposures. In practice, exposures to firms remain the focus, due to the existence of consistent granular data across countries.

A first exposure metric is the emissions allowance gap, which captures the difference between firm-level GHG emissions and free allowances in the European Emissions Trading System (ETS). An important monitoring and public policy mechanism in GHG emissions has been the introduction of a cap-and-trade system with the EU ETS. It has led firms to pursue decarbonisation efforts relative to a global baseline (Bayer and Aklin, 2020). Each year, firms within the scope of the EU ETS must surrender a number of emission allowances corresponding to their emissions. They receive a decreasing number of free allowances every year and are required to make up the shortfall by buying allowances on primary or secondary markets. The reform of the EU ETS resulted in a large jump in 2013, followed by a decrease in recent years reflecting decarbonisation trends (Chart 1, left). The number of free allowances varies by sector, resulting in a concentration of potential losses due to a carbon price increase within a small number of sectors (Chart 1, right).

The gap between free allowances and GHG emissions can be used as a firm-specific metric of exposure to potential changes in carbon prices. Based on the characteristics of the firms participating in the EU ETS, a € 100 increase in carbon prices would entail combined losses of more than € 30 billion for firms in the mining, energy, food manufacturing and transportation sectors.⁵ While these estimates to some extent reflect the size of the sectors within the EU ETS scope, the losses expressed as a share of operational revenues show that individual energy firms would be hit particularly hard (Chart 1, right). The proposed extension of the EU ETS scope to other

⁵ Apart from sectoral concentration, the potential impact of a carbon price increase varies between countries, reflecting the size of the industries in each country.



sectors suggests that the corporate sector's exposure and sensitivity to carbon prices could increase going forward.⁶

A second exposure metric is loan-weighted emission intensity, which measures the carbon intensity of bank lending to economic sectors. A metric commonly used to monitor climate-related transition risk is the average emission intensity of credit exposures (loan-weighted emissions intensity of a portfolio).⁷ As a starting point, production-based emission intensities can be employed, i.e. the loan-weighted Scope 1 emission intensity of bank exposures (Chart 2, top left), making use of publicly available emissions data, combined with aggregate data on banks' balance sheets. The results indicate that differences between countries are mainly due to the contributions of the energy, waste, transportation and agriculture sectors. A comparison of loan-weighted emission intensity with a simpler summary of country emissions over country gross value-added (GVA) shows that banks' loan exposures are tilted towards emission-intensive sectors in all countries (Chart 2, top right). Building on this approach, as well as more granular emissions and credit registry data, emissions estimates can be used to obtain intensities that extend beyond production to the related energy consumption (i.e. computing loan-weighted emission intensity based on firm-level emissions combined with firm revenues rather than sectoral GVA). The results provide a slightly different country ranking (Chart 2, bottom left). In both cases, in countries with high levels of loan-weighted emission intensity, the main contributions come from mining, manufacturing and electricity. These sectors account for almost 60% of the total at euro area level. Looking at developments over time, the loan-weighted emission intensity (emissions over revenues) was broadly stable between 2015 and 2019 and increased significantly during 2020, driven by the sharp fall in corporate revenues during the outbreak of the COVID-19 pandemic (Chart 2, bottom right). To provide a financial stability perspective based on exposure metrics, a first angle is to relate the climate-related vulnerability of emission intensity to financial vulnerability metrics such as indebtedness. Only a few economic sectors, namely energy, agriculture, mining and transportation, combine high Scope 1 emission intensity with high indebtedness (Chart 3, bottom left) when breaking down the evolution of the emission-to-loan ratio over time.

⁶ See European Commission: “**Fit for 55: Delivering the EU's 2030 Climate Target on the way to climate neutrality**”

⁷ Loan-weighted emission intensity at the sectoral level is defined as GHG or CO2e emissions over gross value-added (GVA), weighted by sectoral loan-share: $\sum_s E_s / GVA_s \times L_s / L$, with E_s representing emissions and L_s loans by sector, where L stands for total loans. The **IMF Climate Change Indicators Dashboard** labels the indicator “Carbon Footprint-Adjusted Loans to Total Loans” (CFALTL). See Box 1 for an analogous loan-weighted approach examining flood risks for Italian firms.

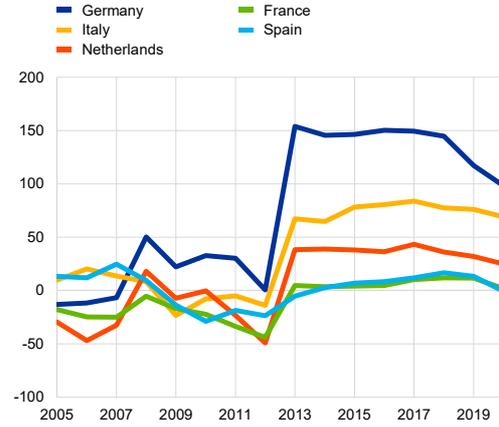


Chart 1

Firm-level exposures to changes in emissions allowance prices

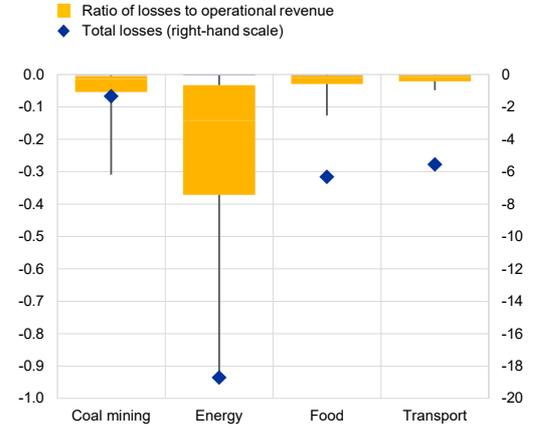
a) Emissions allowance gap in selected euro area countries

(CO₂-equivalent tons)



b) Impact of a €100 increase in carbon prices on firms in EU ETS scope relative to operational revenue

(percentages, by sector)



Sources: ECB, ESMA, Union Registry data.

Notes: Left-hand panel: sum of GHG emissions gap, calculated as the difference between the number of allowances that need to be surrendered and the number of allowances received for free, by firm domicile. The increase in 2013 marks the beginning of Phase 3 of the EU ETS. Right-hand panel: impact of a €100 increase in carbon prices on firms from four different sectors within the EU ETS scope. The four sectors make up 93.8% of the GHG emissions of firms within the EU ETS scope (which covers Scope 1 emissions only). Total losses based on the GHG emissions gap at firm level are displayed as a % of operational revenue by sector.

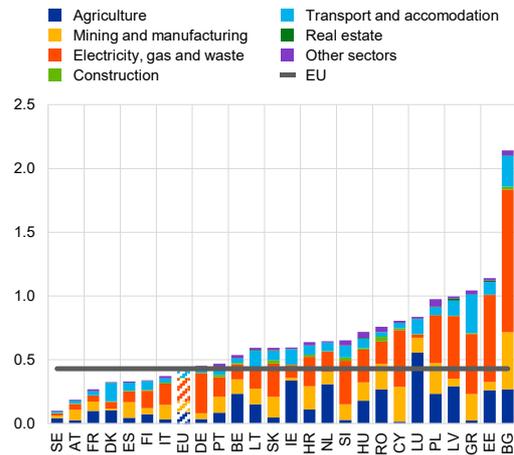


Chart 2

Bank exposure metrics – loan-weighted emission intensity

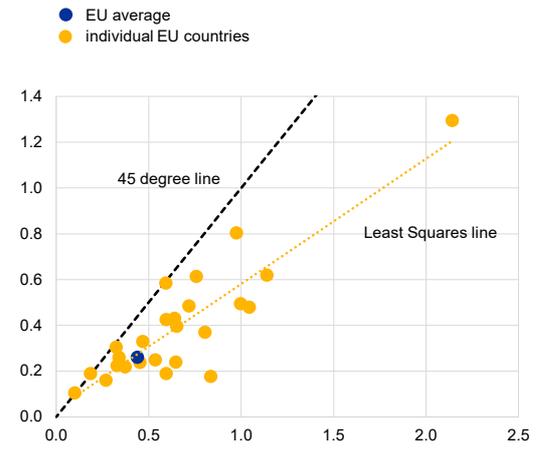
a) Loan-weighted Scope 1 emission intensity by sector and country

(y-axis: kg of CO₂e per euro of GVA, 2020)



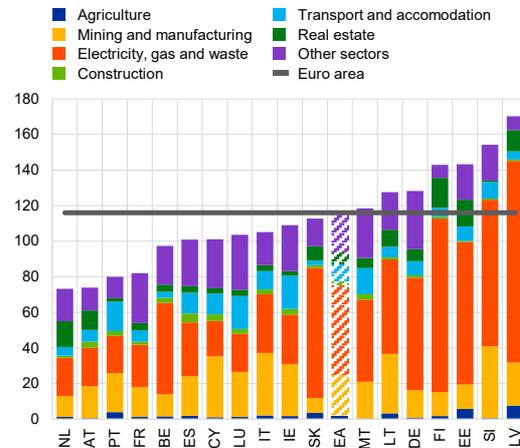
b) Bank loan portfolio tilted towards emission-intensive sectors (Scope 1 emission intensity)

(y-axis: kg of CO₂e per euro of GVA, x-axis: loan-weighted emission-intensity, 2020)



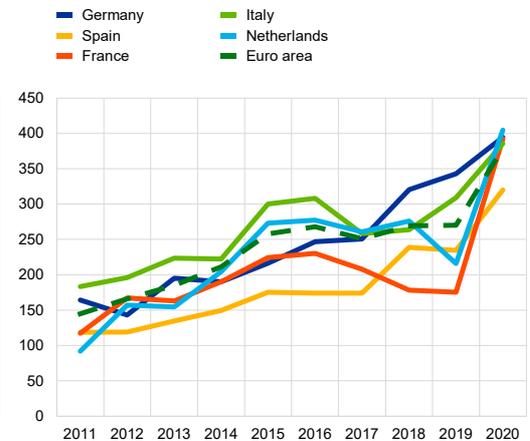
c) Loan-weighted scope 1 and 2 emission intensity computed at firm level and aggregated by sector and country

(y-axis: kg of CO₂e per € 1,000 revenues, 2020)



d) Loan-weighted Scope 1 and 2 emission intensity over e

(y-axis: kg of CO₂e per € 1,000 firm revenues)



Sources: Top - Eurostat, ECB (Consolidated Banking Data), Banco de Portugal calculations, Bottom: AnaCredit, Urgentem, ECB calculations.

Notes: Top Czech Republic omitted due to lack of data for loans by NACE sector. The corresponding Carbon footprint-adjusted loans to total loans (CFALTL) features in the [IMF Climate Change Indicators Dashboard](#). Bottom left: sample of loans reported in AnaCredit with reported or inferred emissions for the borrower. Bottom right: subsample of loans reported in AnaCredit with reported emissions (around 5.000 firms, balanced sample).



Box 1

Physical risk exposures and the relevance to account for damage

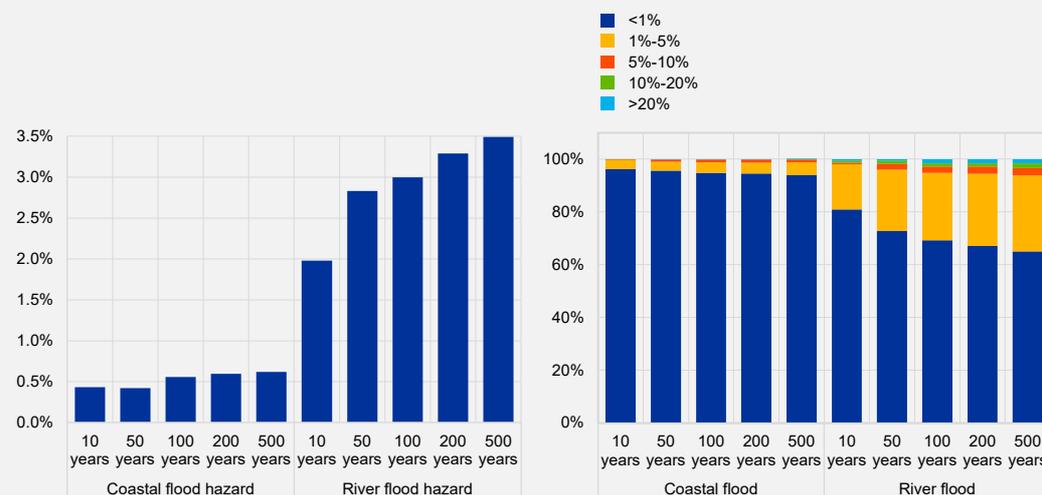
The share of loan exposures of Italian banks to firms located in areas of flood risk relative to total loans can serve as a flood risk exposure metric. Flood risk is a major driver for physical risk in Italy, but no more than 0.6% of banks' loan portfolios are exposed to coastal flood hazard. For river floods, the exposure ranges from 2.0% of loans in a ten-year return period to nearly 3.5% in a 500-year return period (Chart A, left). According to Antofie et al. (2020) the overall average expected annual loss due to both river and coastal flood risk is approximately 0.15% of total credit.

Chart A

Exposure to flood risk in Italy by return period

a) Share of bank loans to firms located in areas at (flood) risk relative to total credit to firms (percentages, AnaCredit loan exposures)

b) Distribution of share of total credit by Italian banks to firms by maximum expected (flood) credit risk and by return period (percentages, share of loan at risk)



Sources: AnaCredit, JRC Risk Data Hub.

Exposure amounts represent an upper limit on potential bank losses, whereas the losses themselves are generally lower, as mitigating factors limit. For the actual loss associated with physical risk, potential damages based on damage functions⁸ must be taken into account. In the case of Italy, the aggregate exposure to coastal and river flood risk is very low, with fewer than 3.5% of outstanding loans at risk of (Chart A, right). Nevertheless, a number of individual small intermediaries with a share of more than 20% of loans at risk could be severely affected, indicating concentration risks.

Data gaps remain an important limiting factor on the assessment of losses on exposures (see ECB/ESRB (2021) for a discussion of data gaps). Such analysis hinges on (i) data on business unit

⁸ Damage functions are necessary to analyse the potential impact of physical risk on bank capital when hypothetical physical risks materialise. Assuming that this percentage also corresponds to the percentage of credit that will not be repaid if a catastrophic event occurs, the expected loss for the intermediary granting the credit can also be calculated.



location (the analysis is conducted at headquarters) and (ii) on the accuracy of the damage functions. Improvements in both areas could significantly enhance the quality of the analysis.

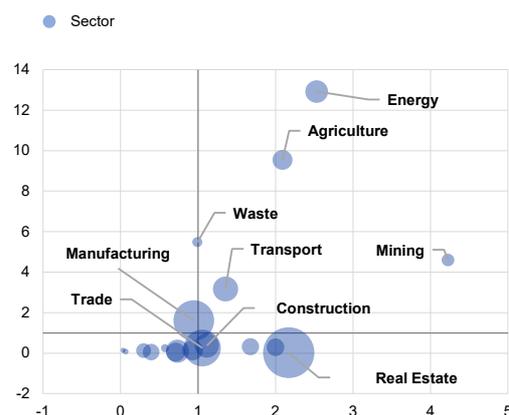
A third exposure metric is loan-carbon intensity, which captures the overall emission intensity of bank lending.⁹

For EU countries, loan carbon intensity declined steadily, by 23% in the five years to 2019, broadly indicating that loan efficiency increased, reducing the exposure of banks to transition risk per unit of loan (Chart 3, right). This decline was driven by a shift in loans towards less emitting sectors (in blue, since 2016) and, a decrease in the emissions themselves (in red, since 2017). At the same time, the breakdown also shows a decrease in the headline indicator: an important part of decline in the headline value stems from the nominal increase in loan volumes (in yellow).

Chart 3
Emissions and the role of sectoral indebtedness

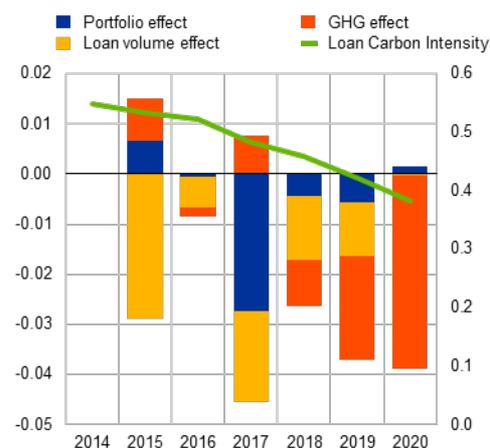
a) Scope 1 emission intensity and indebtedness across sectors in the euro area

(y-axis: kg of CO₂ per euro of gross value-added (GVA), x-axis: loans over GVA, bubble size indicates the share of total loans by sector, 2020)



b) Loan Carbon Intensity

(y-axis: annual changes with contributions in kg of CO₂e per euro of GVA (left-hand scale), LCI (right-hand scale), 2014-2020)



Sources: Eurostat, ECB (Consolidated Banking Data), Banco de Portugal calculations.

Notes: CZ omitted due to lack of data for loans by NACE sector. The portfolio effect refers to the contribution of changes to the share of loans by sector.

A fourth exposure metric takes a different approach, leveraging transition needs across economic sectors into an EU taxonomy-based metric.¹⁰

An alternative method in assessing the exposure to transition risk in financial portfolios is based on the EU taxonomy for sustainable activities. The transition-risk exposure coefficients (TECs) of Alessi and Battiston (2021) indicate

⁹ Loan carbon intensity is defined as emissions over credit or loans in a financial portfolio and characterizes the emission efficiency of credit exposures.

¹⁰ Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment and amending Regulation (EU) 2019/2088 (OJ L 198, 22.6.2020, p. 13).



the share of activities in each NACE¹¹ sector which need to transition, either because the activity is linked to fossil fuels or because it is particularly energy-inefficient. A portfolio's transition risk exposure is obtained by applying to each loan or security the TEC associated with the main sector of activity of the individual borrower or investee company.¹² Based on the security-by-security calculation, green (taxonomy-aligned) financing amounts to 1.3% of total exposures in the EU financial market. In turn, the share of transition risk exposures is 5.5% and has been broadly stable since 2014 (see 'Total' in Chart 5, left).¹³ The exposure to transition risk of institutional investors in particular stands at 1.7%, 5.0%, 4.1% and 6.1% for banks, insurers, pension funds and investment funds, respectively (see Chart 4, right).

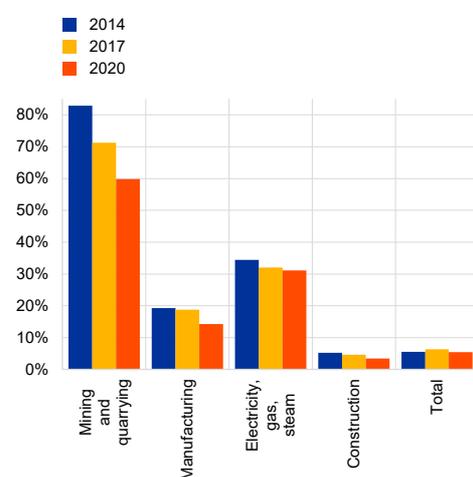
While the overall share of transition risk exposures has remained stable, the share of financing directed towards activities that are more exposed to transition risk within relevant sectors (e.g. mining and quarrying) has decreased. This indicates that in a given sector, investors increasingly prefer to invest in activities that are relatively greener or at least do not significantly contribute to climate change (see Chart 4, right). Focussing on financial sectors, the transition-risk exposure of banks, insurers, pension funds and investment funds was increasing until around 2017: however, the trend reversed in the period to 2020, except in the case of financial vehicle corporations.

Chart 4

Transition exposure-based metrics

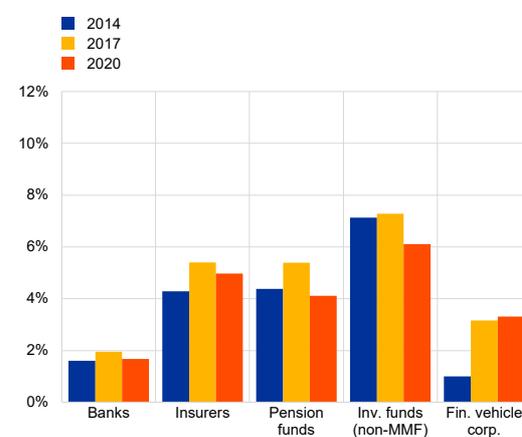
a) Share of transition risk exposure of financial investments into selected economic sectors

(percentages)



b) Share of transition risk exposure of selected financial investor types

(percentages)



Sources: ECB Securities Holding Statistics and further calculations based on TECs proposed by Alessi and Battiston (2021).

Notes: The bars represent the share of bonds and equities exposed to transition risk based on the TEC coefficients developed

¹¹ NACE is the **Statistical Classification of Economic Activities in the European Community**.

¹² Taxonomy alignment is estimated using coefficients at NACE four-digit sector level developed by Alessi and Battiston (2021), which are mainly based on technical screening criteria used in the EU Taxonomy Regulation (**Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088** (OJ L 198, 22.6.2020, p. 13).

¹³ The share of 5.5% comprises all securities but the share of equity exposures subject to transition risk is nearly double at around 10%.



by Alessi and Battiston (2021). These coefficients reflect the share of activity in each economic sector which will need to transition, e.g. because it is linked to fossil fuels, or is particularly energy inefficient. This information is used to characterise the transition risk of a security issuer, then combined with the actual amounts of securities traded on European markets.

As well as the corporate sector, climate-related financial risks can also emanate from households and sovereigns. The climate-related exposures of households and sovereigns remain relatively under-explored, compared with those of firms. As noted in Box 2, the data by households for Ireland show that the nature of the exposures may differ from that of corporate exposures: income and geography become important factors in determining transition risk. A more detailed discussion of risks from these institutional sectors is provided in Chapter 3.2 of this report.

Box 2

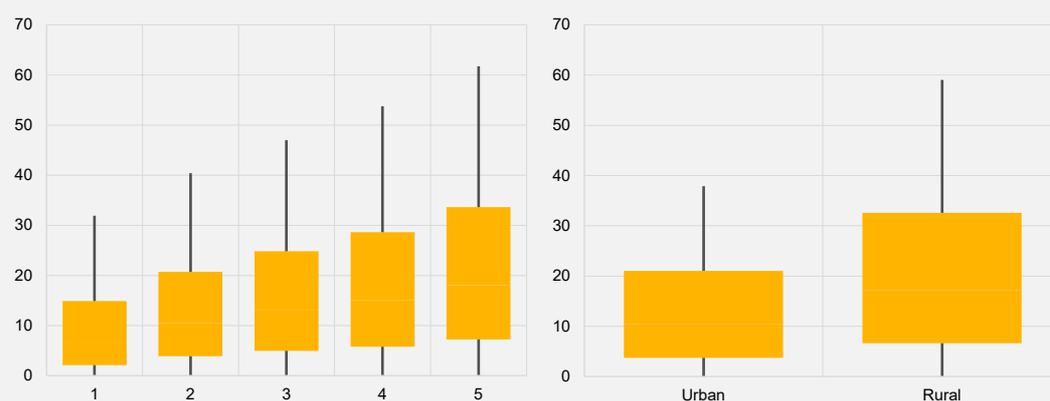
Financial sector exposure to household transition risk – an application to Ireland

Future energy price increases, whether driven by policy or market forces, will affect energy costs, with possible implications for household financial resilience and credit risk in the banking sector. The measurement of financial sector exposure to household transition risk is inhibited by data gaps. National credit registers (or the loan-level dataset (LLD) in the current context) generally do not contain information on borrower energy consumption or GHG emissions. This box complements such datasets with energy and emission estimates based on energy expenditure in national household budget surveys (HBS), see Annex 1.2.4 for methodological details.

Chart A

Distribution of annual household energy emissions by gross income and location (urban/rural)

(tonnes of CO2 emissions per year; left panel: x axis – income quantiles, y axes both panels – annual household emissions)



Source: Irish Central Statistics Office Household Budget Survey 2015/2016 and Project Team calculations.

Note: CO2 emissions are estimated using expenditure for electricity, gas, oil, petrol, diesel and solid fuels, common prices for each fuel in 2015/2016 and emission conversion factors for each fuel for Ireland.

There is considerable variation in household energy consumption and emissions, particularly between incomes and property locations. Annual CO2 emissions rise with gross income (Chart A,



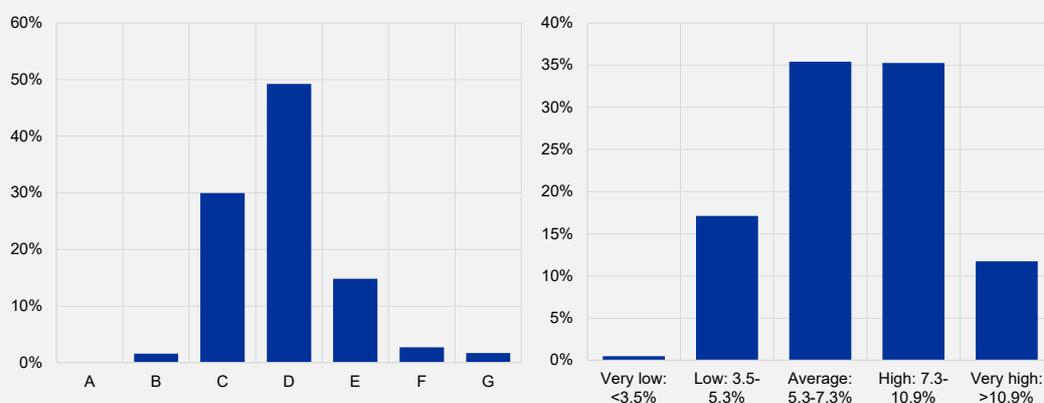
based on Irish HBS sample) and the number of rooms and occupants in a property. For example, mean CO₂ in the highest income group (top quintile – 12.4 tonnes) is over double that of the lowest income group (lowest quintile – 5.9 tonnes), while each additional room and adult-equivalent increases emissions on average by 1.6 and 2.5 tonnes, respectively. Location is also a driver – average rural household emissions are 51% higher, probably due to large property size (+14% rooms), more car fuel use (+66% petrol/diesel) and slightly more occupants (+3.4%).

Turning next to our estimate of CO₂ in the loan-level environment (excluding transport emissions), Chart B (left-hand panel) presents the share of bank mortgage loans (by value) within each indicative energy performance certificate (EPC) category.¹⁴ This estimate is based on a borrower’s income, age, province, and property size/type. It is clear that banks are exposed to high-energy/emission households: 68% of borrowers are estimated to be within the “D” or lower categories. While this share is higher than national EPC statistics (45% “D” or lower), the difference is partly due to higher income (a determinant of our energy estimate) in the mortgage sample compared with the wider population. Chart B (right-hand panel) presents an alternative risk metric: the share of mortgage loans by energy (estimated) cost-to-income ratios (category bounds are based on quintile points for mortgaged households in the HBS). Almost half (48%) of outstanding mortgage values are to borrowers in the “high” or “very high” energy cost-to-income categories.

Chart B

Share of outstanding mortgage balances by estimated EPC rating (left-hand side) and energy-to-income ratio categories

(left panel: x-axis – estimated EPC rating, right panel: x-axis – energy to income ratio quintiles, y-axes both panels – share of outstanding balance (percentage))



Source: Irish Central Statistics Office Household Budget Survey 2015/2016, Central Bank of Ireland (random sample of new mortgage loans from 2018 (n = 10,000)).

Notes: EPC categories (left-hand side) are created from CO₂ emissions estimates, which exclude transport (petrol and diesel expenditure). EPC CO₂ bounds for each EPC category are taken from the National BER Database (Sustainable Energy Authority of Ireland). The five energy-to-income ratios (right-hand side) category bounds are based on HBS quintiles for the national sample.

This method provides an initial estimate of household/bank exposure to transition risks. We note that the feasibility of extending this method to other countries depend on the availability of energy

¹⁴ EPC CO₂ bounds for each EPC category are calculated from the national database.



data in the credit register and the relevant survey data. However, given the accessibility and cross-country consistency of the HBS, it is likely that the exercise can be replicated in other countries. Alternative approaches are possible, but would require new data collections, either through the existing credit register data collection processes or through a new, regular household survey. The method can serve as a platform to explore broader financial stability implications in the context of rising energy costs through carbon pricing.

2.2.2 Risk and vulnerability metrics

Financial institutions

Linking climate risk exposures to traditional sources of financial vulnerability can provide insight into financial risk relevant for financial institutions. The climate-related vulnerability metrics discussed in Section 2.1 of this report (exposures to transition risk, or alternatively physical risk) can be linked to the traditional financial vulnerabilities of borrowers and the sensitivities of credit risk parameters (such as leverage, provisions or synthetic probabilities of default of non-financial corporations). This section discusses two such measures: notably, one measure combining standard financial vulnerability metrics with climate transition elements, and another assessing climate risk sensitivity based on ECB climate stress testing model parameters.

A first financial vulnerability metric –Transition-to-credit risk-intensity (TCI) – combines banks’ loan exposures with firm’s emissions and probabilities of default (PD)¹⁵. The GHG emissions capture vulnerability to climate transition risk, while the PD measure overall credit risk. Overall, the higher a firm’s contribution to the TCI score aggregated at the bank level, the greater the mutual amplification of transition and credit risk on that particular exposure, assuming that the PD does not capture the full extent of the transition risk. The TCI provides complementary results on banks’ exposure to transition and financial risk, in addition to the loan carbon intensity ratio.¹⁶ While the loan carbon intensity ratio can be used to assess to what extent carbon-intensive firms are financed by loans, the TCI also brings in the financial risk angle.

¹⁵ See Annex 1.2.3 for the detailed formula.

¹⁶ The bank-level loan carbon intensity ratio is calculated by aggregating (i.e. taking the sum of) borrowers’ emissions and dividing them by the total value of the bank’s corporate loan portfolio (see Section 2.2.1).



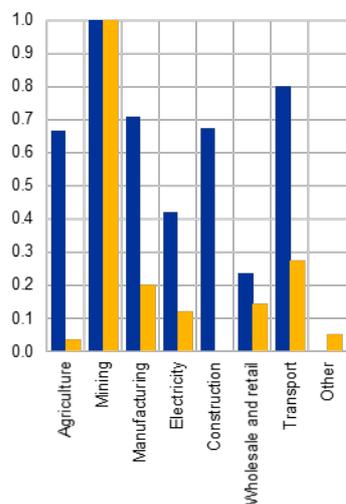
Chart 5

Transition-to-credit risk-intensity (TCI)

a) Breakdown of euro area TCI compared with emissions-over-loan ratio and by NACE-sector in 2018

(y-axis: normalised, weighted average sector-level TCI scores and emission-over-loan ratios by sector in 2018)

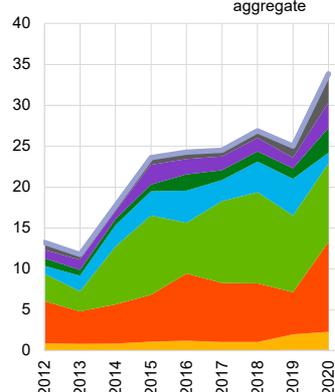
■ Transition to credit risk intensity
■ Loan carbon intensity ratio



b) Breakdown of euro area TCI by NACE-sector over time

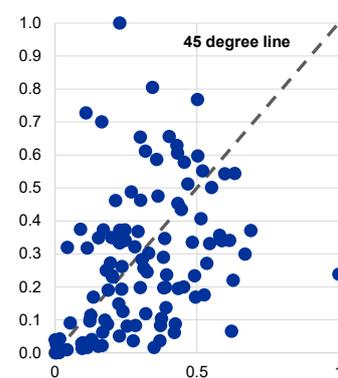
(y-axis: sectoral shares of euro area TCI aggregate, 2012-2020)

■ Agriculture ■ Wholesale and retail
■ Mining ■ Transport
■ Manufacturing ■ Other
■ Electricity ■ Euro area aggregate
■ Construction



c) TCI score and emissions-over-loan ratio for banks in 2018

(y-axis: normalised emissions-over-loan ratio, x-axis: normalised TCI score, sample covers significant institutions)



Sources: Urgentem, AnaCredit (2019), Register of Institutions and Affiliates Data (RIAD) and ECB calculations.

Notes: Emissions refer to firm-level relative and absolute (loan carbon intensity) scope 1, 2, and 3 emissions. Panel a) comprises inferred emissions for around 2.5 million firms in 2018, covering around 80% of total AnaCredit exposures. Panel b) covers both inferred and reported emissions for 1,250 firms, which comprise on average 10% of AnaCredit exposures over time. NACE: Nomenclature statistique des activités économiques dans la Communauté Européenne (Statistical classification of economic activities in the European Community).

The distribution of sectors in the TCI score differs – in some cases considerably– from the distribution in loan carbon intensity. While the agricultural sector has one of the strongest TCI scores, this is mainly due to prevailing financial risk as its loan carbon intensity is almost negligible. On the other hand, mining has a loan carbon intensity almost four times larger than the second most intensive transportation sector. This difference is less pronounced in the TCI, which is only around 1.25 times higher for mining relative to the transportation sector (Chart 5, panels a and b). In terms of dynamics, the TCI level has gradually increased over the last seven years amid rising sectoral emissions (Chart 5, panel b). The mining, manufacturing, construction, wholesale and transport sectors together contributed almost 70% to the euro area average TCI in 2013, compared with 60% in 2020, while the electricity sector increased its share from 25% to 37% at the end of the period. At the bank level, while the TCI broadly correlates with the loan carbon intensity, differences in the scoring of individual entities suggests that the TCI can provide complementary information (Chart 5, panel c).

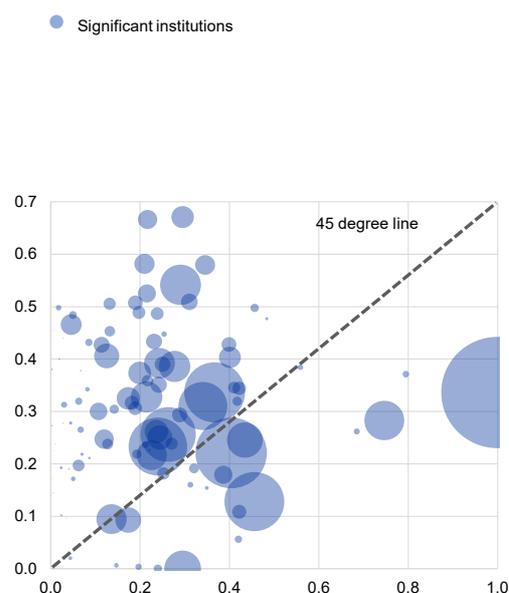


Chart 6

Climate risk-driven expected losses and link to portfolio- and system-level expected losses

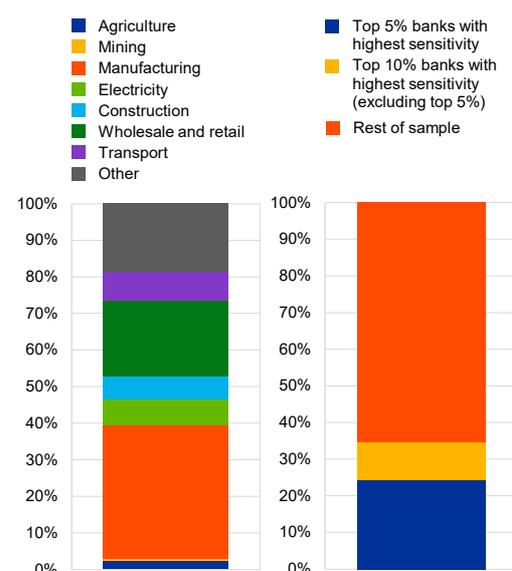
a) Relationship between climate risk concentration and climate risk-driven expected losses for euro area banks in 2019

(y-axis: share of portfolio exposures to high emitters firms; ratio, x-axis: normalised CRS score, size of bubbles represents expected losses in absolute terms; ratio)



b) Sectoral concentration of expected losses due to climate risk in 2019 in the euro area

(y-axis: share of system-wide expected losses by NACE sector; percentages (left-hand scale) and by sensitivity to carbon prices (right-hand scale))



Sources: ECB calculations on Orbis, AnaCredit, NGFS and Urgentem data (2019).

Notes: NACE: Nomenclature statistique des activités économiques dans la Communauté Européenne (Statistical classification of economic activities in the European Community).

The concentration of climate-related risks is an important factor in the assessment of individual bank portfolios as well as from a system-wide perspective. By leveraging model parameters developed in the ECB economy-wide climate stress test,¹⁷ it is possible to identify banks that would be hit particularly hard by expected losses stemming from transition risk. The CRS metric captures the relative increase in expected losses – defined as the product of exposures, probability of default and loss given default triggered by an increase in carbon prices¹⁸. The price increase implies a deterioration of borrower PD due to higher operating costs, lower profitability and higher leverage, given asset deteriorations and the need for green technology investments.¹⁹ The metric is calculated as part of the Network for Greening the Financial System (NGFS) (2021) disorderly transition scenario and captures the increase in expected losses due to higher carbon prices over a 30-year period.

¹⁷ See Alogoskoufis, S., et al. (2021), “ECB economy-wide climate stress test – Methodology and results”, Occasional Paper Series, No 281, ECB, September.

¹⁸ See Annex 1.2.3 for the detailed formula.

¹⁹ The CRS has similarities to the transition vulnerability factor developed by De Nederlandsche Bank (DNB) (2018) in that both metrics incorporate a sensitivity parameter (beta) which measures the reaction of either expected losses (CRS) or stock returns (TVF) to forward-looking transition risk in the form of carbon price increases.



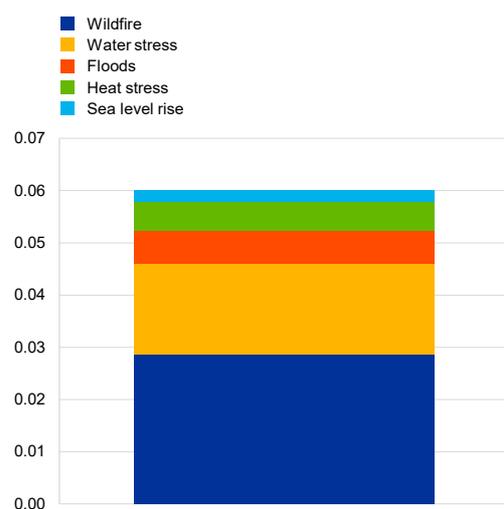
The combination of financial vulnerability with climate-related vulnerability might also be an issue in terms of physical risk. A physical-to-credit risk intensity (PCI), accounting for the physical dimension of climate risk, varies considerably by geography.²⁰ The PCI thus captures a combination of physical risk and firms that are vulnerable in terms of their credit risk. The metric can be calculated by replacing (firm-level) emissions with (firm-level) vulnerability to natural hazards using physical risk scores.²¹ Based on the PCI, 11% of loan exposures are to firms with high physical and financial risk (Chart 7, left). These loans are predominantly held by firms vulnerable to wildfire risk, followed by water stress and flood risk. The resulting metric is heterogeneous between countries, reflecting the geographical dimension of physical risk and the higher concentration of physical risks in southern European countries (Chart 7, right).²²

Chart 7

Physical-to-credit risk-intensity (PCI) score

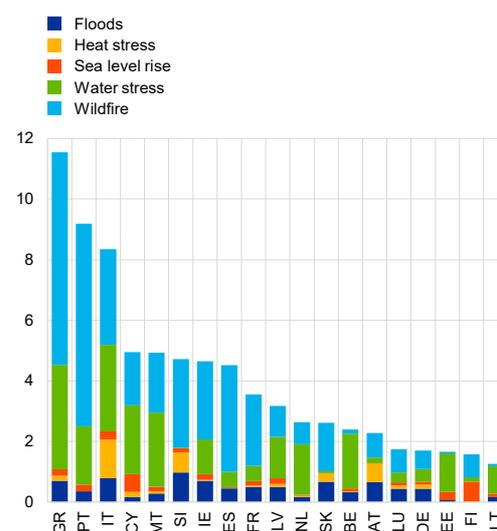
Share of loan exposures towards high risk borrowed to (PCI) tail risk firms in 2019

(y-axis: share of loans within top 10% of highest PCI scores; percentages)



Share of loan exposures towards high risk borrowed to (PCI) tail risk firms in 2019

(y-axis: weighted by country-level loan exposures; x-axis euro area countries)



Sources: ECB calculations on AnaCredit and Four Twenty Seven data (2019).

Notes: Loans are defined as low (medium) risk if their PCI score falls below the 40th (80th) percentile of the distribution, while tail risk firms are those with loans above the 80th percentile.

²⁰ See Annex 1.2.3 for the detailed formula.

²¹ Firms' vulnerabilities to natural hazards are measured with firm-level data based on risk scores from Four Twenty Seven. The risk scores provide information on the frequency and severity of different types of weather events to which firms are exposed. These scores are forward-looking and are measured according to the address level of the firms' production facilities based on the scores of sub-hazards. For floods, for example, this includes rainfall, while for wildfires it takes into account heat and humidity, so some degree of the interdependencies of the different sub-risk types are accounted for.

²² It is important to note that the physical risk scores do not account for existing mitigation measures, such as firms' insurance coverage against natural hazards.



Financial markets

There is emerging evidence of a link between climate-related disclosures and financial stability through credit risk.

An empirical analysis of climate-related disclosures shows that the act of disclosing emissions and reductions in disclosed emissions intensity are associated with better credit ratings, after controlling for firm-specific characteristics and various fixed effects (Carbone et al., 2021). These benefits are likely to decrease once mandatory disclosure is extended to a larger number of EU firms (see below). Moreover, forward-looking commitments to reduce emissions are also associated with higher ratings, with larger effects in the case of more ambitious emissions reduction targets. Firms disclosing targets tend to reduce emissions more than other firms, particularly if these are "science-based" targets (Chart 8, left).

Progress in terms of the disclosure of the impact of ESG factors on credit ratings remains uneven, however.

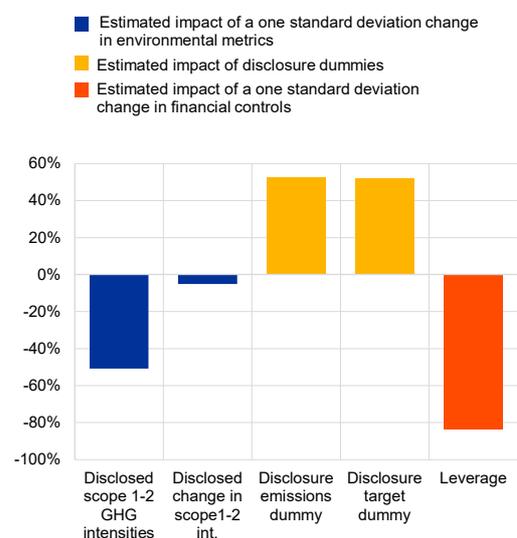
An analysis of 64,000 press releases from credit rating agencies shows that ESG disclosures increased by around 60% after the introduction of the ESMA guidelines on disclosure (Amzallag et al., 2022). However, the improvement remains limited when it comes to environmental considerations, with only 11% of press releases published since March 2020 containing a meaningful discussion on environmental topics (i.e. three or more environmental words). Meanwhile a high degree of divergence can be observed between rating agencies, highlighting the need for additional transparency (Chart 8, right).

Chart 8

Climate-related disclosures and credit risk

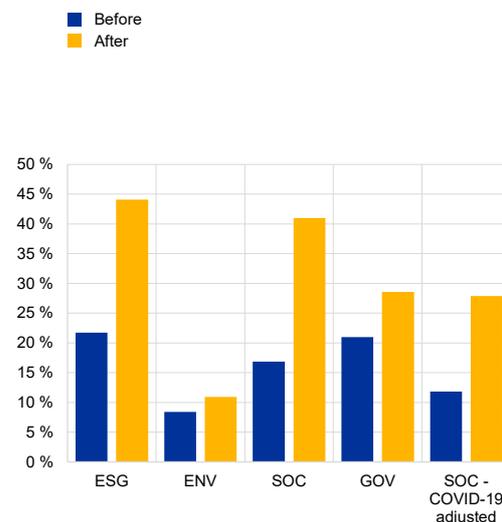
a) Impact of disclosure on credit rating

(y-axis: credit rating notch impact; percentages)



b) ESG disclosures in credit rating agency press releases before and after introduction of disclosure requirements

(y-axis: press releases; percentages)



Sources: ECB, ESMA.

Notes: Left: Estimated impact of disclosure on credit rating notches. Right: Percentage of credit rating agency (CRA) press releases with at least six ESG words (75th percentile of the distribution of ESG words per press release) in the 9 months before and after the entry into force of ESMA Guidelines on CRA disclosure, and at least 3 ESG words for the environmental, social and governance specific factors.



Box 3

Corporate GHG emissions: availability and consistency of firm-reported data

Corporate GHG emissions data underpin a large number of analyses related to climate change, including firms' transition risk and ESG ratings. This box sheds light on data quality and consistency across five data providers. Data from commercial data providers MSCI, Refinitiv, Urgentem (Papadopoulos 2022) and ISS show that coverage of existing firms is increasing, but low overall. For EU-domiciled firms, disclosed total emissions²³ in 2019 amount to 865 corporate groups across the four providers, representing around half of the amounts of Eurostat's annual Air Emissions Accounts (Chart A), covering around €6 trillion in revenues and with 40% of the total number of firms from the manufacturing sector.²⁴ Coverage significantly increased in 2020 for ISS.²⁵

Chart A

GHG emissions across providers

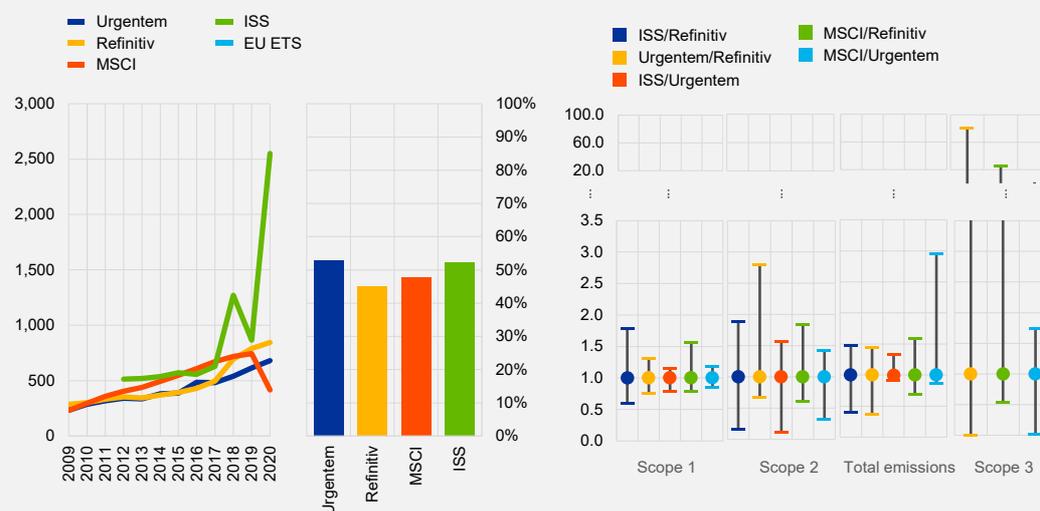
(panel a: x-axis: GHG emissions coverage across providers; left-hand y-axis: number of firms; right-hand y-axis: percentage of Eurostat's annual Air Emissions Accounts in 2019; panel b): x-axis: pairs of GHG mission providers; y-axis: ratio; percentage)

a) GHG emissions coverage across providers

b) Box-plot of firm reported CO₂e emissions data ratios between pairs of different data sources

(x-axis: GHG emissions coverage across providers; left-hand y-axis: number of firms; right-hand y-axis: percentage)

(x-axis: pairs of GHG mission providers; y-axis: ratio, percentage)



Sources: Refinitiv, MSCI, Urgentem, ISS, European Commission, Eurostat.

Notes: Left: Number of companies reporting total emissions by commercial data provider. The bars show the share of European air emissions accounts (Eurostat) covered by Scope 1 emissions across the commercial datasets and EU ETS in 2019. The strong decline in MSCI figures in 2020 is due to the database vintage used in the analysis, before the completion of

²³ Sum of Scope 1 and Scope 2 GHG emissions, based on the GHG Protocol.

²⁴ Generally, the most represented countries are France, Germany, Italy and Sweden and the most represented sector is manufacturing across sources and within countries.

²⁵ The trend is mainly driven by financial corporations. The provider emphasised a dramatic improvement in data quality and availability due to increased awareness of climate among stakeholders.



the update cycle for that year. Right: Circles denote the median and whiskers the top/bottom 5th percentile of the distribution of firm-reported data ratios for each pair of data providers. Scope 3 ratios refer to the RHS axis. Firms which reported zero emissions have been included in the ratio calculations.

While emissions data are broadly comparable across sources, sizeable discrepancies may exist between pairs of individual data providers (Chart A). These are less pronounced for Scope 1 emissions where discrepancies in most firm-reported figures are within a 30% range. Discrepancies increase for Scope 2 and total emissions (scopes 1 and 2), where data from different providers may differ by a factor of three. Finally, inconsistency in Scope 3 emissions can reach two orders of magnitude. A similar pattern across scopes can also be found when considering correlations. For Scope 1 emissions, the correlation is at least 0.94 across providers. The figures drop to about 0.5 for Scope 2 and are close to zero for scope 3 emissions²⁶. These findings suggest that cross-firm analyses based on Scope 1 emissions data would be the least affected by inconsistencies. Given the widespread use of estimates, results based on Scope 2 and, particularly, on Scope 3 emissions data demand a higher level of caution.

A sectoral analysis shows that discrepancies across providers remain contained for the most represented sector, the manufacturing sector. However, the discrepancies are present regardless of the level of firms' GHG emissions, ranging from low to high emitters alike. An important source of heterogeneity is the degree of consolidation of firms, which ranges from the facility level (for EU ETS²⁷) to corporate group level.

Despite their fundamental role, emissions data remain sparse and subject to quality issues. Key elements to improving data quality are stricter disclosure requirements, validation of emissions data (audit), harmonization and transparency. To that end, regulatory measures such as the proposed CSRD and the establishment of the European Single Access Point are important steps forward (see more detailed discussion in Section 4 of this report).

2.3 Financial market-based and system-wide metrics

Beyond individual exposure and climate-related risk metrics, system-wide aspects may affect the assessment of financial stability risks. Several dimensions of system-wide aspects are considered: interdependencies and correlations among transition and physical risk factors, interdependencies of among firms and economic sectors, and, lastly, overlapping portfolios among financial institutions. All these types of interdependencies may amplify individual risks, putting financial stability at risk.

²⁶ The highest correlations are found between ISS-Refinitiv, followed by Refinitiv-Urgentem and ISS-Urgentem. Correlations between reported Scope 3 information were possible between Refinitiv, Urgentem and MSCI (reported Scope 3 emissions in ISS are only available for 2020).

²⁷ The Union Registry is a centralised database that holds annual verified CO₂ emissions for 17,503 installations (i.e. 11,005 account holders) participating to the EU Emissions Trading System (EU ETS).



2.3.1 Interdependent exposures and risks

Transition risk is a common risk factor and can affect all firms and exposures

contemporaneously. An increase in the cost of carbon, be it through a carbon tax or other market mechanisms, affects the valuation of firm-level assets and firms' creditworthiness (see the CRS metric in Section 2.2.2). As it is a common factor, it can give rise to clustered defaults across firms. Transition risk thereby not only alters the size of individual firms' credit parameters, but also the correlation of defaults across firms.

An increase in the cost of carbon raises existing default correlations across firms,

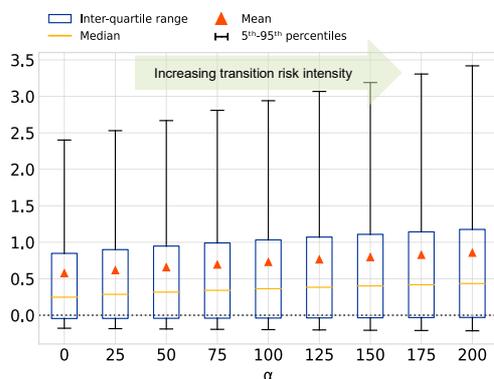
particularly for high emitters. Based on historical data from Moody's Analytics²⁸, the distribution of pairwise firm default correlations²⁹ stands at 0.5% (median at 0.24% and 95th percentile at 2.4%). An increase in the price of carbon by €200/tCO₂ results in the average correlation almost doubling, from 0.5% to 0.9% and an increase from 2.4% to 3.5% for the 95th percentile (Chart 9, left)³⁰.

Chart 9

Correlation structure with increasing transition risk

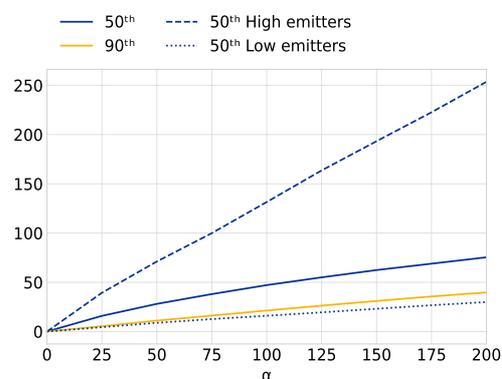
a) Default correlations distributions for increasing transition risk intensity α

(x-axis: α – transition risk intensity; y-axis: correlation; percentage)



b) Growth of cost of carbon for increasing transition risk intensity α

(x-axis: α – transition risk intensity; y-axis: increase; percentages)



Sources: Moody's Analytics and ECB calculations.

Note: The parameter α incorporates both the transition risk shock T (in €/tonCO₂) as well as a pass-through factor β capturing the degree to which firms can pass the cost of a transition risk shock to consumers (Belloni et al., 2022).

²⁸ The sample comprises all EA firms available in the intersection of Moody's Credit Edge and Urgentem (over 1,300), with probabilities of default in the baseline referring to end-2021.

²⁹ The analysis estimates the impact of transition risk on firms' default correlations via a multi-firm Merton model calibrated on historical data. In particular, 500,000 Monte Carlo iterations are used to simulate the correlated default paths of each individual firm, and the associated defaults are estimated via a standard KMV corporate default model. See the annex for more details on the modelling framework.

³⁰ The magnitude of the shock is determined by transition risk intensity α which captures both an increase in carbon cost (such as that arising from a tax on carbon emissions) as well as a pass-through factor denoting the degree to which firms can pass the cost on to consumers. Under the simplifying assumption that a firm would bear the full cost of an increase in carbon prices, the transition risk intensity α simply captures the increased cost in €/tCO₂.



Apart from correlations driven by the exposure of firms to the increase in cost of carbon, higher emitting firms would tend to default jointly more frequently. This is confirmed by splitting the sample of firms into high and low emitting firms³¹ and analysing the median correlation for these two groups for intensifying transition risk (Chart 9, right): the default correlations of high emitting firms increase substantially compared with those of low emitters.

This changing default correlation has implications for the possibility of diversification within the financial system. The increase in the correlation due to transition risk particularly affects previously weakly correlated exposures, which have been relevant for mitigating bank-level risks. The stronger correlation among firms limits the possibilities for loss diversification and may amplify unexpected losses in banks' portfolios, representing a source of systemic risk.

Like transition risk, a clustering of physical hazards may also exacerbate financial stability risks due to firms' vulnerability to multiple hazards. Natural hazards are characterised by interdependencies either in the form of correlations or causal links (Chart 10, left) which may generate self-reinforcing feedback mechanisms. For example, heat stress can cause wildfires, which in turn both increase the likelihood of more wildfires and exacerbate heat stress. Future intensification of climate risk may give rise to hard-to-price tipping points and impair the ability to diversify, potentially posing risks to financial stability.

The financial impact of materialising physical hazards could be amplified by fire sale dynamics. In the event of a sudden reassessment of risks, the joint liquidation of affected securities may affect market prices. A strong price correction may spread common losses across different market participants and result in contagion-induced deleveraging pressures (Cont and Schaanning, 2019). Estimates of the exposure of common asset holdings of market participants (overlapping portfolios) to various physical risks (Chart 10, right) range from 2% of overlapping portfolio assets for hurricanes and typhoons, to an average of 45% for wildfire-weighted portfolios.

Common exposures across institutional sectors can gauge the likelihood of contagion in the event of physical stress. In the event of a sudden reassessment of risks, common holdings may be the first route for systemic risk from physical hazards to materialise, providing a channel for mark-to-market losses to spread between different market segments. This system-wide perspective highlights the relevance of a macroprudential approach to systemic risk management and prudential regulation designed to mitigate the impacts of climate change on financial stability (see Section 4 on policy).

³¹ Here *High emitters* (*Low emitters*) are defined as firms with emissions above (below) the 75th percentile of the distribution of emissions in the sample considered.

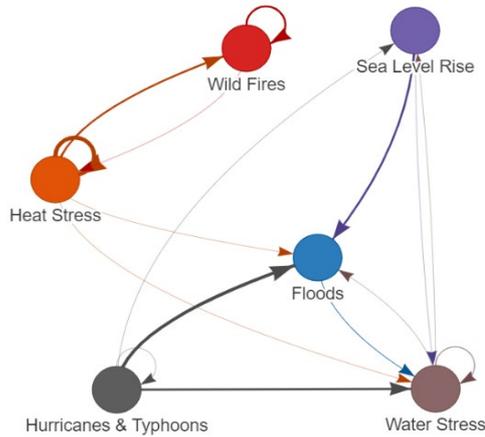


Chart 10

Interdependencies between natural hazards and financial sectors

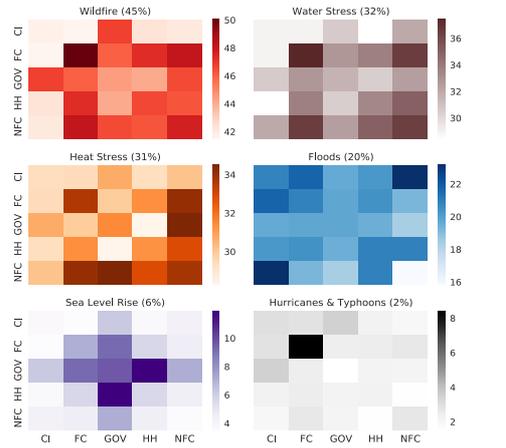
a) Natural hazards interdependencies

(Nodes: natural hazards; Line and arrows thickness: based on correlations and causation between hazards)



b) Physical-risk-weighted overlapping portfolios - share of common asset holdings

(x- and y-axes: sectors; colour shade in percentages; mean overlap by natural hazard in title)



Sources: Left – Data from Gill and Malamud (2014), and ECB calculations. Right – Security Holding Statistics, Four Twenty Seven and ECB calculations.

Notes: Left – Links refer to both correlations as well as causal links. The arrows' thickness is proportional to a score capturing either increased probability or the causal trigger of the hazards, in terms of both spatial overlaps as well as temporal likelihood. Aggregated from (Gill, 2014). Right – Overlapping portfolios weighted by physical hazards scores as share of common asset holdings by aggregate sectors. The physical-risk-weighted overlapping portfolios between sectors i and j are reported as a share of common assets holdings, that is $\tilde{O}_{ij} / O_{ij} = \sum_k \Pi_k (S_{ik} \wedge S_{jk}) / \sum_k (S_{ik} \wedge S_{jk})$ where S_{ik} denotes the holdings of sector i of security k , and Π_k the physical risk weight associated with the issuer of security k . The sectors considered are credit institutions (CI), financial corporates (FC), governments (GOV), households (HH), and non-financial corporates (NFC). Securities include both bonds and equities.

2.3.2 Real economy impact of climate risk and financial interlinkages

While reaching carbon neutrality will involve adjustments particularly in sectors most exposed to transition risk, cascading effects could engulf other sectors. As economies are interdependent, the impacts of the direct exposure of a sector or firm to transition risks may be amplified by second-round effects stemming from interconnections between sectors and countries. Multi-Regional Input-Output (MRI-O) data captures these intersectoral real economy interdependencies and account for direct and indirect channels. This section considers a sectoral input-output setting by Cahen-Fourot et al. (2021) to analyse the implications for the financial system.³²

³² We are grateful Emanuele Campiglio (University of Bologna) and Antoine Godin (Agence Française de Développement (AFD)) for providing insights and data input for the real economy simulations.



In the case of the transition, the economic implications depend on whether the adjustment is driven by policy or market-induced supply or demand shocks.³³ The two channels are independent, representing two different ways in which the transition can be transmitted and amplified due to interdependencies across sectors.³⁴ The analysis first of all considers adjustments in the form of a supply shock specific to the fossil fuel sector in which fossil fuel production factors fall by 10 to 30% over five years³⁵ and, second, the implementation of policy measures, such as the introduction of a carbon tax that translates into an immediate demand shock in some specific climate policy-targeted high emitting sectors by the same amount.³⁶ The transmission via a demand shock affects a wider-range of sectors before being able to effectively reduce carbon emissions, while the implementation via fossil fuel supply restrictions would be more focused but with economy-wide implications.³⁷

The economic sectors most at risk in case of a supply shock on fossil fuel are naturally those directly related to coal, petroleum, and gas. While the direct effect is the dominant driver for extraction sectors, second-round effects are more relevant for sectors processing petroleum and gas or producing electricity from petroleum and gas. These indirect effects could be very significant, with, for example, a 30% decrease in fossil fuel production factors translating into a total fall in production for the petroleum refineries of more than 80%. The stronger indirect exposure of these downstream sectors can be explained by the fossil fuel intensity of the intermediate inputs they use. The total impact on GVA of this energy-specific shock would not exceed 0.8% in the case of a 30% supply side reduction, but this initial shock is amplified by a factor of ten as it propagates through the supply chain (Chart 11, left).

In the case of the policy-induced demand shock targeting high emitters, several sectors would be directly affected with second-round effects revealing the still significant dependency of our economies on fossil fuels. A 30% reduction in demand in climate policy-targeted sectors translates into a fall in production for air transport by 38%, when accounting for indirect effects. The coal, petroleum and gas extraction sectors are now less directly affected but suffer more from second-round effects as the other sectors adjust and reduce their demand for fossil fuel inputs. On aggregate, the euro area GVA loss is estimated at 1.25% for a 30% decrease in demand in carbon intensive sectors, with 50% of the overall impact explained by second-round effects (Chart 11, right).

³³ The shocks transmit through the value chains, creating second-round effects along the way. Each shock is expressed as a range of potential decrease in demand or supply and translated into its associated economic and financial impacts. The results should be interpreted only as measures of the exposure of sectors to supply or demand shocks associated with the transition to a low-carbon economy and not as predictions or scenario analysis.

³⁴ The two scenarios can be added together, but the calibration of the shocks would need to be revisited to avoid potential double-counting.

³⁵ As a reference, the NGFS Climate Scenarios Database indicates that fossil fuel consumption may have to fall by up to 27% over five years, depending on the scenario.

³⁶ The climate policy-targeted sectors selected here include the five sectors covered by the Carbon Border Adjustment Mechanism (i.e. electricity, iron and steel, fertilisers, aluminium and cement), with the addition of the extraction (petroleum, gas and coal) and transport (air transport and land transport except trains) sectors. The initial 10% to 30% demand shock in these sectors is distributed between them depending on their respective direct and embodied CO2 emission intensities. See the annex for more details.

³⁷ It is important to note that the static approach taken here neglects macroeconomic factors. It does not account, for instance, for the impact on temporary unemployment or real income that a supply shock may have and the implications on aggregate demand.



Chart 11

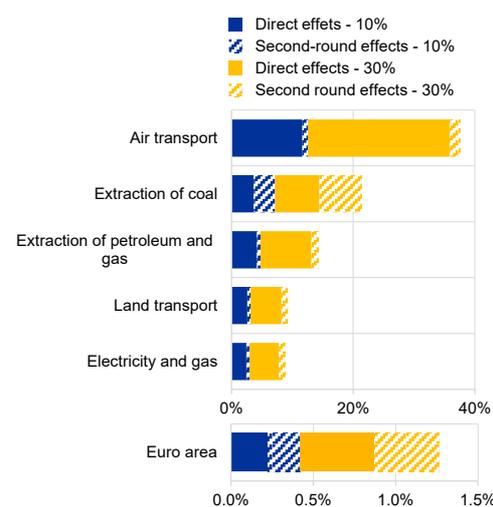
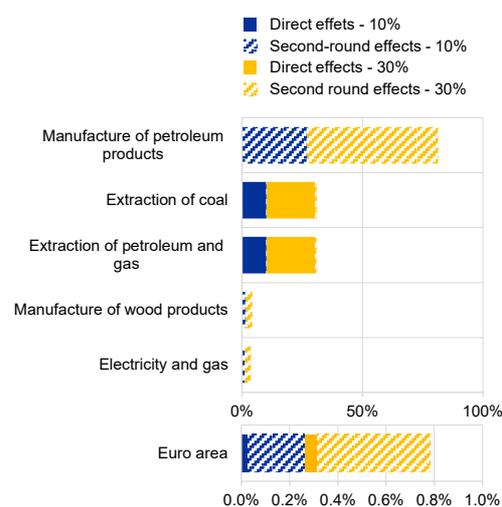
Euro area sectoral impacts of supply and demand shocks

a) Supply shock – Sectoral impacts in the euro area following a 10 to 30% decrease in fossil fuel production factors

b) Demand shock – Sectoral impacts in the euro area following a 10% to 30% decrease in demand for climate policy-targeted sectors

(x-axis: percentage share of production)

(x-axis: percentage share of production)



Source: Authors' calculation with partners.

Note: Results for the five most affected sectors only.

The impact of supply and demand shocks on the banking sector is assumed to be transmitted via credit risk parameters (probability of default).

Accordingly, a sectoral decline in output is assumed to proportionally increase the PD of firms in the respective sector. It implies that the sectoral output losses in each euro area country from input/output interdependencies provide the information for proportional PD increases. Firms more (less) vulnerable to a transition shock would see more (less) deterioration in their credit quality in proportion to their output loss.

A breakdown of exposures shows that exposures of banks to vulnerable sectors is limited, particularly in the case of supply shocks.

Most bank exposures to sectors vulnerable to a supply or demand shock are concentrated in the electricity and gas sector, which is only the fifth most affected sector for both supply and demand shocks (see Annex section 1.3.1, Chart A.1). The eastern European countries as well as Greece are relatively more exposed with exposures to sectors vulnerable to both demand and supply shocks exceeding 2% of total assets for Latvia, Slovakia, and Greece. However, exposures to vulnerable sectors are low overall, with the euro area average exposure to vulnerable sectors not exceeding 1% of total assets.

The loss impact on banks arises from two main transmission elements.

First, the aggregate impact on GVA differs between the two scenarios with the demand shock exerting a larger aggregate impact. Second, the distribution between the affected sectors differs between the two analyses, with the supply shock having a more concentrated and the demand shock a more widespread impact. Below, we carry out a sensitivity analysis by applying a range of PD increases



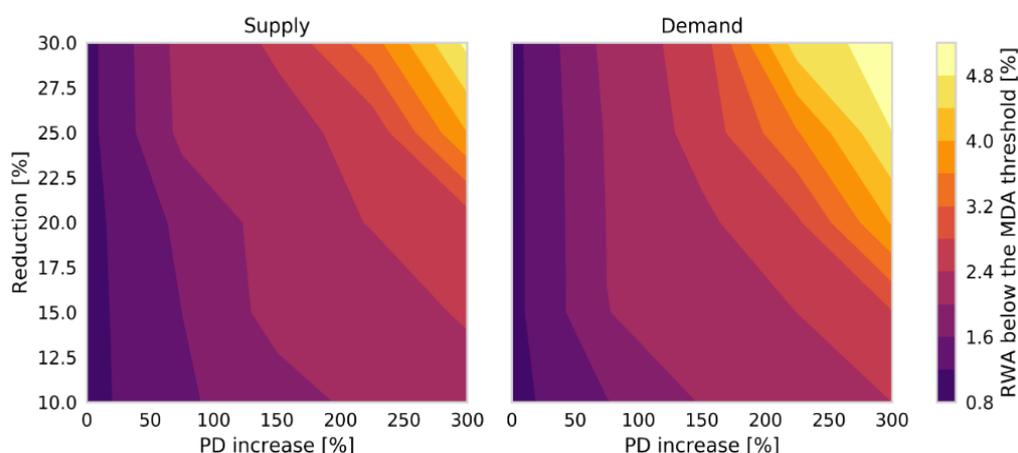
to sectors with a decrease in output of 0.5 p.p., where sectors with a (higher) decrease in GVA are shocked relatively (more) less.

Due to the differing sectoral impact of transitional demand and supply shocks, the aggregate banks' balance sheets are more sensitive to policy measures affecting demand.

The broader range of sectors affected by the demand shock increases PD markedly across sectors. In the case of a 30% reduction of fossil fuels via supply shocks and a 300% PD increase up to 4.5% of euro area banks' risk-weighted assets (RWA) are estimated to fall below the maximum distributable amount (MDA) threshold (Chart 12, left, blue dot). In the case of the demand shock the banking system results are, however, more vulnerable due to which an increase of sectoral PD of 200% would already imply that 4% of banks' RWA would fall below the MDA threshold (Chart 12, right, blue line). The banks' RWA is estimated not to exceed 5% with a 30% decrease in supply and demand and a 300% PD increase applied to sectors with a 0.5 p.p. GVA decrease in an expected (average) scenario. However, in the case of a tail scenario, up to 12% and 20% of banks' RWA are estimated to fall below the MDA due to supply and demand shock, respectively, given a 30% reduction and a 300% increase in PD (see Annex 1.3.2, Chart 3).³⁸

Chart 12
Banks' risk-weighted assets (RWA) below the MDA threshold

a) Supply shock – banking system impacts following a 10% to 30% reduction in fossil fuel production factors (percentages of total euro area risk-weighted assets)
b) Demand shock – banking system impacts following a 10% to 30% reduction in global demand (percentages of total euro area risk-weighted assets)



Sources: Supervisory data, Security Holding Statistics, Exiobase, and ECB calculations.

Notes: Increases in PD refer to increases for firms hit by an average euro area output loss, with the credit quality associated with higher (lower) output loss deteriorating proportionally more (less). The sample includes 2,130 banks comprising significant institutions and less significant institutions. Cf. Annex 1.3.1 for further details.

Impacts arising from adjustments in the supply and demand channels reflect the sectoral GVA losses of these shocks, the pre-existing creditworthiness of borrowers and the

³⁸ Where an expected or average scenario is defined as the mean CET1 ratio post-contagion over all simulations, a tail scenario is defined as the mean over the simulations that fall between the 93rd and 97th percentile in terms of system-wide losses.



complexity of the exposures network of banks. While supply and demand shocks impact differently on sectors, exposures concentrated in specific sectors contribute to rebalance the relative importance of sectors for banks' balance sheets. For example, the sizeable share of banks exposures towards the electricity and gas sector makes it of primary importance, despite it being relatively less affected in terms of GVA losses, with respect to other sectors. Analysing the interaction between the economy quantity channel (with no price effect) and banks' risk exposures therefore provides a more holistic framework to assess the vulnerability of the banking system to transition risk.

2.3.3 Estimated banking system losses due to transition risk

Apart from materialising credit losses, climate risk may transmit to banks through the risk assessment of portfolios in terms of adjustments of RWA. Such transmission may represent a systemic amplifier if accompanied by bank balance sheet adjustments through asset revaluation and fire sales. When transition risk materialises at the same time as other financial stress, unrelated to climate factors, it can generate additional losses for the banking system.³⁹ To quantify the transmission channel, the analysis first considers an environment of financial stress, unrelated to climate factors. In a second step, banks and other investors shed risky assets exposed to transition risk (Alessi et al., 2022). To capture transition risk, banks adjust the risk weights of assets exposed to transition risk to reflect the increased riskiness of high-carbon and fossil fuel activities.⁴⁰

The increased riskiness of high-carbon and fossil fuel activities – captured by an increase of RWAs - may contribute to an additional 8% of EU losses in case of financial stress comparable to the global financial crisis, when fire sale dynamics are not included. This amount represents losses of 0.2% of total banking sector assets. The additional losses would be unevenly distributed across countries, reaching up to a 40% increase for some EU countries (see Chart 13, left). A sensitivity analysis shows that these results strongly depend on the precision of the assessment of transition risk exposures in banks' balance sheets.

Transition risk might not only generate additional losses in a crisis scenario but could also trigger banking sector losses through fire sales of assets exposed to transition risk. In such a constellation, the banks would be under stress because of their exposure to high-carbon assets and would adjust their balance sheet by shedding assets. For this, the model assumes an initial sell-off of assets exposed to transition risk equal to 5%, which leads to a decline in the market valuation of high-carbon assets. Even a very limited initial depreciation (0.3% of their value) could trigger a series of further valuation adjustments and amplify bank stress, ultimately resulting in losses of up to 1% of total assets for the EU banking sector as a whole (Chart 13, right). These losses would again be concentrated in countries that are more exposed to transition risk.

³⁹ A micro-simulation model based on individual bank balance sheet data is used to generate crisis scenarios and derive the aggregated loss distribution for the banking sector, see Annex 1.3.2 for methodological details.

⁴⁰ In line with the literature, high-carbon assets are assumed to be between 15% and 25% more risky than other assets. On the increased riskiness of fossil-fuel firms, see Alessi et al. (2022).

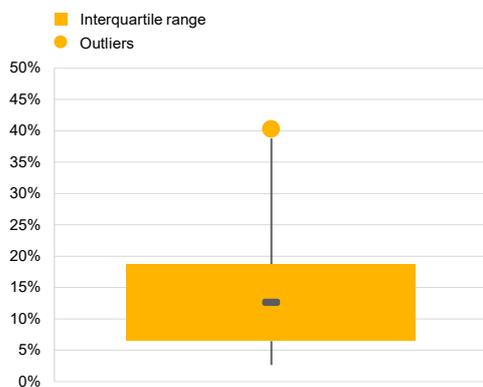


Chart 13

Losses in the banking system

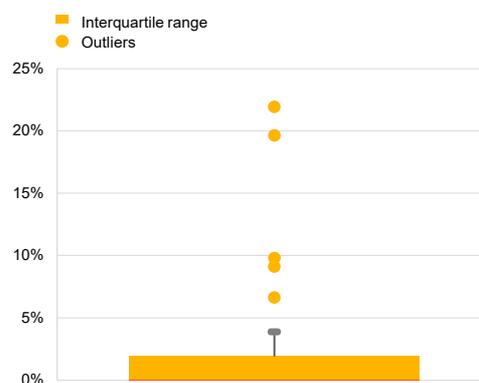
a) Box plot of loss increase due to transition risk between countries in the case of a banking crisis

(y axis: loss increase, percentages)



b) Box plot of losses (as a percentage total assets) due to a fire sale of high-carbon assets

(y-axis: losses as % of total assets; percentages)



Sources: JRC calculations.

Notes: In the box plots the black thick line in the boxes represents the mean (13% in left panel and 3% in right panel). The white middle line of the boxes represents the median (8% in left panel and 0% in right panel). The bottom line of the boxes represents first quartile (6% and 0% in right panel). The top line of the boxes represents the third quartile (19% in left panel and 1% in right panel). The whiskers extend from the ends of the boxes to the minimum value and maximum value, excluding outliers (any value exceeding 1.5 times the interquartile range). All EU countries are considered in the sample.

A gradual greening of bank balance sheets could reduce overall losses by more than 90%, as it would reduce the riskiness of the portfolio and the likelihood and impact of fire sales.

Such "greening" of banks' balance sheets could naturally result from the greening of underlying activities and would not require an active sale of assets. As the aggregate losses are concentrated in a few banks, a reduction of concentrated exposures to transition risk would be more effective than a homogeneous reduction across all banks.⁴¹

⁴¹ See also the box on the calibration of capital buffers based on the same study.

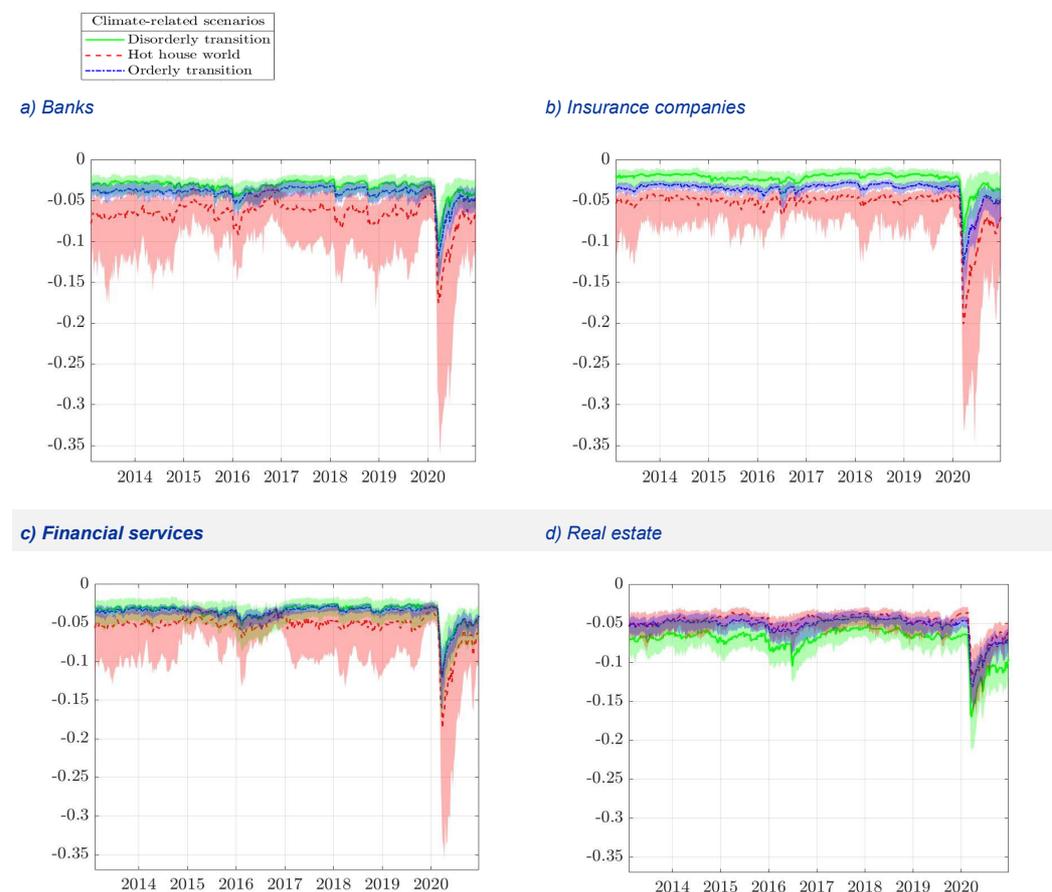


2.3.4 Climate transition risk measure for financial firms

Chart 14

Climate transition value-at-risk (CTVaR) at the financial sectoral level

(x-axis: years; y-axis: log returns)



Source: Ojea-Ferreiro, Reboredo and Ugolini (2022).

Notes: These charts show the median CTVaR within each subsector (solid line) together with the interquartile range of the cross-section distribution (area). The red colour denotes the hot-house world scenario, green refers to the disorderly transition and blue the orderly transition. The CTVaR is calculated by looking at the 10th percentile of the conditional distribution.

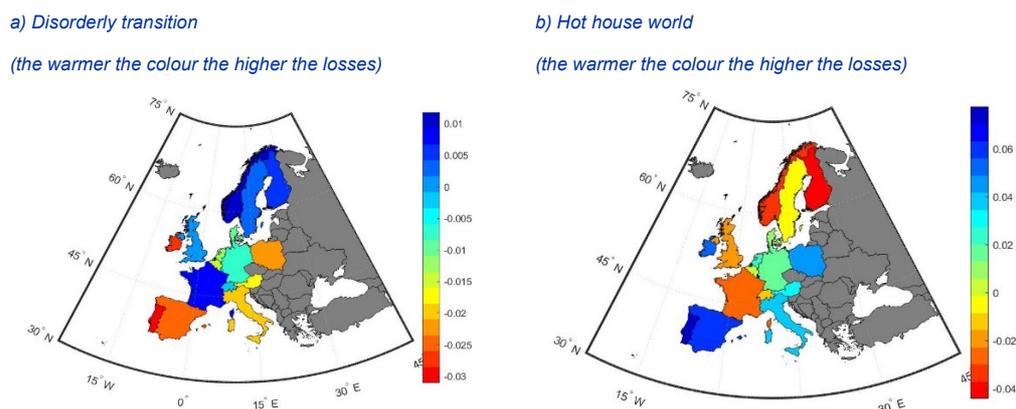
Transition risk can cause sudden market price readjustments, if unanticipated. One possible way of quantifying the financial market effects of transition risk uses the distribution of firm returns, conditional on the materialisation of specific transition scenarios (Ojea Ferreiro et al., 2022). The disorderly transition, orderly transition and hot house world scenarios from NFGS (2020) can trigger specific asset repricing, captured by a combination of movements in three market portfolios (green, neutral and non-green carbon intensive) on the basis of the underlying financial firm's returns.⁴² This enables quantification of the effect of transition scenarios on the financial firms' value in order

⁴² The non-green/neutral/green portfolios have a high/ medium/ low climate transition exposure, respectively. The relationship between the portfolios and the various financial firms is captured by means of a copula model. More details about the setup can be found in the annex.



to obtain conditional distributions of financial firm returns.⁴³ On the basis of the conditional distributions, it is possible to derive climate transition metrics such as the climate transition expected return (CTER), climate transition value at risk (CTVaR), and climate transition expected shortfall (CTES).

Chart 15
Climate transition expected return (CTER) at country level



Sources: Ojea Ferreiro, Reboredo and Ugolini (2022).

Notes: These charts show the weighted average CTER using the relative market capitalization as a weight factor over the sample. The warmer the colour, the higher the losses. The focus is on transition risk only.

Empirical evidence for European financial firms indicates that banks would experience the greatest impact in a disorderly transition scenario. The median CTVaR in the period 2013-2020 (Chart 14)⁴⁴ points to higher losses for the banking sector in the disorderly transition scenario than in the hot-house world scenario. Also, the capital requirements of the European banking sector derived from the CTER could reach € 140 billion during periods of high volatility.⁴⁵ Insurance, financial services and real estate would suffer most in a hot-house world scenario, which would also have more heterogeneous effects than a disorderly transition, as shown by the wider bands. Indeed, while the difference between the 25th and the 75th percentile of the cross-section distribution is 5% for the banking sector, the difference for the non-banking sector in the interquartile range for the banking sector ranges from less than 5% (disorderly transition) to more than 15% (hot-house world). At the country level (Chart 15), financial systems in Southern Europe, Ireland and Poland would be most affected by a disorderly transition, whereas France, the United Kingdom and the Scandinavian countries would be most exposed in a hot house world scenario. Stock profits in the hot-house scenario are 500 basis points higher than profits in the disorderly

⁴³ These metrics are technically similar to conditional risk measures available in the literature (Adrian and Brunnermeier, 2016; Girardi and Ergun, 2013; Acharya et al., 2017; Brownlees and Engle, 2017), although in this setup the trigger is provided by the combined impact of green, neutral and non-green carbon intensive portfolio returns.

⁴⁴ VaR is a non-additive measure, therefore the graphs are more informative when we consider interquartile range.

⁴⁵ The capital shortfall under a particular climate transition scenario is obtained from an adaptation of the methodological framework of Brownlees and Engle (2017), where the CTER substitutes the marginal expected shortfall (MES).

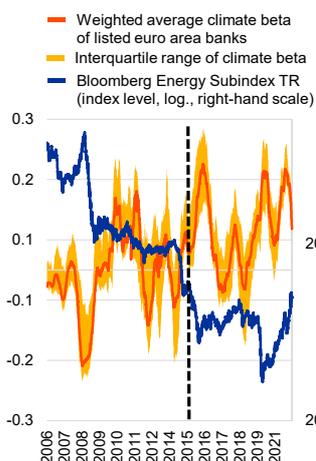


transition scenario, as shown by the heat bar of the figures. This indicates a different quantitative outcome for the two opposite extreme scenarios.

Chart 16
Climate betas and CRISK of euro area banks

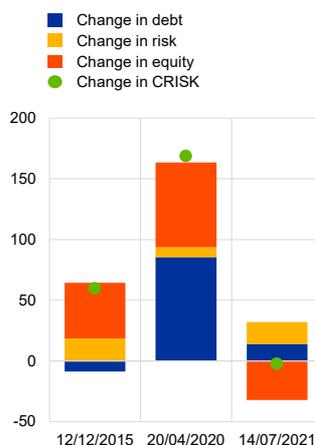
a) Climate betas for banks

(y-axis left scale: climate beta, y-axis right scale: log-level; x-axis: 2006–22)



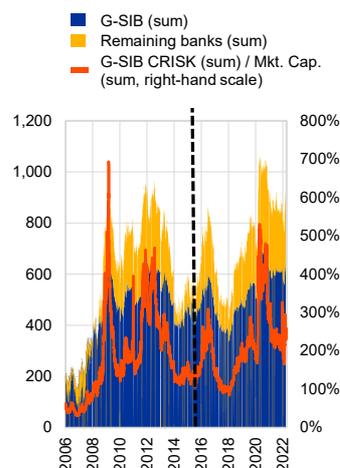
b) CRISKS for euro area banks

(y-axis left scale - in EUR billion)



c) Decomposition of G-SIBs' CRISK around key (climate-related) events

(y-axis left scale - in EUR billion; y-axis right scale - in percentage of market capitalisation)



Source: Bloomberg, ECB calculations.

Notes: Panel a): Sample of 40 listed euro area banks. The climate betas are based on six-month moving averages of daily data. The red line shows average climate betas for all banks in the sample, weighted by market capitalization. The vertical dashed line indicates the adoption of the Paris Agreement on 12 December 2015. Panel b): the decomposition follows the methodology of Jung, Engle and Berner (2022) and is based on a symmetric six-month window around event dates. The change in CRISK is due to its climate risk component (banks' climate betas and climate factor volatility). Panel c): CRISK based on six month moving averages of climate betas. We classify the following balanced sample of banks as G-SIBs: BNP Paribas, Deutsche Bank, Crédit Agricole, ING, Banco Santander, Société Générale and Unicredit. The vertical dashed line indicates the adoption of the Paris Agreement on 12 December 2015. The red line shows the ratio of the aggregate G-SIB CRISK to their market capitalisation. Chosen dates correspond to the following events: 12/12/2015: Paris Agreement; 20/04/2020: Front month WTI oil futures price turns negative. 14/07/2021: European Commission adopts a series of legislative proposals setting out how to achieve climate neutrality in the EU by 2050.

An additional metric to capture the systemic nature of transition risk through financial market data is the CRISK indicator developed by Jung, Engle and Berner (2022). CRISK reflects the resilience of banks to climate transition risk by measuring the expected market capital shortfall of a bank in the event of a 50% decline in a *climate factor* – constructed on the basis of



fossil fuel prices⁴⁶ over a six-month horizon. ⁴⁷The CRISK indicator is a function of a bank's climate beta which measures the sensitivity of a bank's stock price to variations in a climate factor.⁴⁸

The climate betas of euro area banks – capturing the sensitivity of bank equity prices to the climate factor - have increased in recent years. The increase, based on a sample of 40 listed euro area banks, points to higher climate transition risk, especially since the 2015 Paris Agreement. It further reflects the negative correlation with prices of energy commodities, i.e. prices of stranded assets (Chart 16, left). Climate betas vary distinctly over time, but their cross-bank variation appears more contained. Currently, the climate betas of most banks appear elevated when compared with their historical values but stand below previous peaks – in line with the recent surge in energy prices.

The banks' market-based capital shortfalls under a climate transition stress event, measured by CRISK, spiked during times of financial turmoil but currently remain below levels of the recent peaks (Chart 16, right). The euro area banks' expected absolute market capital shortfalls are predominantly concentrated among G-SIBs in the case of a climate stress scenario. Overall, CRISK increased significantly during the great financial crisis and euro area sovereign debt crisis, as well as during phases of depressed prices of stranded assets, such as in 2016 or in early 2020, when euro area banks' CRISK briefly exceeded €1,000 billion. On the contrary, recent geopolitical events and the related surge in energy commodity prices led to a sizeable decline in CRISK to around €800 billion, reflecting the lower probability that fossil fuels will become unviable quickly. A breakdown analysis (Chart 16, middle) confirms the importance of increasing climate betas as a driver of CRISK around key transition risk event such as the adoption of the Paris Agreement in 2015, when the CRISK of euro area G-SIBs increased by around €60 billion, of which around one-third was due to increasing climate betas.

2.4 Risk mitigation

Financial risks from transition and physical risk can in theory be mitigated and diversified.

The ideal way to mitigating physical risks over time is through an orderly transition, but other mitigating factors exist. At an individual entity level, risk management techniques such as hedging, and collateralisation can mitigate the impact of climate-related shocks. They can also help to build system-wide resilience by limiting potential amplification channels. However, in practice the choice of financial instruments or techniques to manage climate risk exposures is currently limited.

⁴⁶ The climate factor used in this box is the Bloomberg Energy Subindex Total Return, capturing prices of energy commodity futures, including crude oil, natural gas and petroleum.

⁴⁷ CRISK is the expected market capital shortfall of a bank and follows the same methodology as SRISK with the climate factor added as a second factor in a two-factor model of banks' stock return. $CRISK_{it} = k D_{it} - (1 - k) \exp(\beta_{it}^{climate} \log(1 - \theta)) W_{it}$, where $k = 0.08$ is the (market)equity ratio target, D_{it} is total liabilities, W_{it} is market capitalisation and $\theta = 0.5$ is the climate stress level (a 50% decline here). On SRISK see Acharya, V., Engle, R., and Richardson, M. (2012) and Brownlees, and Engle (2017).

⁴⁸ Climate beta is obtained from a two-factor model also including the market return. It can be interpreted as the sensitivity to a climate factor while keeping the general market index fixed. Betas are estimated dynamically using the dynamic conditional correlations (DCC) model introduced by Engle (2002).



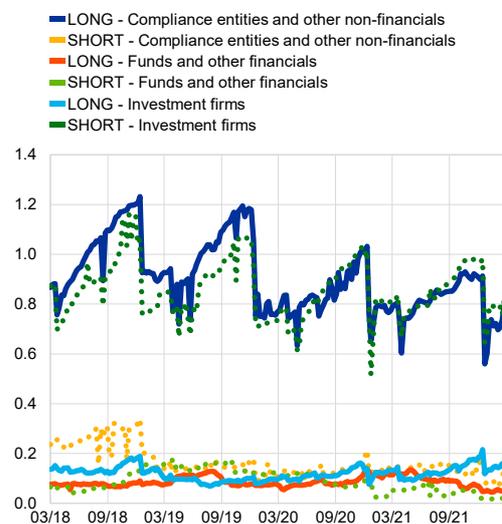
2.4.1 Transition risk mitigation

Rising carbon prices have triggered a debate on the use of EU emissions allowances by financial market participants, including for portfolio hedging purposes. As highlighted in ECB/ESRB (2021), carbon prices play a key role in the management of transition risk exposures. However, the threefold increase in EU carbon prices in the course of 2021 followed by heightened volatility related to the conflict in Ukraine, have raised questions about the impact of financial sector participants on the EU ETS market. In contrast with some other jurisdictions (e.g. China), there are indeed no restrictions on the type of participants that are allowed to trade EU emissions allowances. With the vast majority of trading taking place in derivatives markets (60% in futures with maturities longer than six months and 30% in options, ESMA, 2022), financial institutions play a key role as liquidity providers on the short side, trading with non-financial sector entities under an obligation to surrender emissions allowances once a year (Chart 17, left). While the participation of investment funds and other financial sector entities that are either seeking exposure to carbon prices or looking to hedge their portfolio carbon risk has increased in recent years, the market remains dominated by non-financial corporates and investment firms, accounting for more than 90% of the open positions in emission allowance derivative markets (Chart 17, right).

Chart 17
EU carbon markets

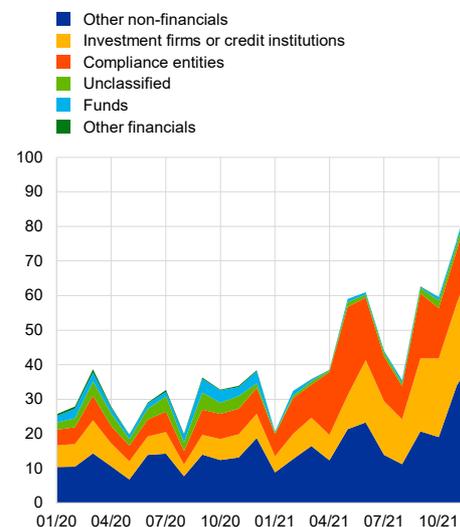
a) Net positions in EU emission allowance derivatives

(x-axis: weekly dates; y-axis: 1,000 tCO₂ - contract lots)



b) Derivatives notional amount traded of EU emission allowances

(y-axis: EUR billions)



Sources: EMIR, Weekly Commitment of Traders, ESMA.

Notes: Panel a): weekly net long and short positions in EU emission allowances derivatives per type of market participant, in lots (1,000 tCO₂). Panel b): monthly notional amounts traded of derivatives contracts on EU emission allowances, split by sector of trading counterparties. Transactions with central counterparties are excluded. The dotted bar marks the UK withdrawal date from the EU.



The use of EU emission allowances for portfolio hedging purposes by financial market participants has so far been limited. This is reflected in the limited share of financial entities taking long positions in futures beyond the next-December expiry. Indeed, while emission allowances present useful features for financial institutions looking to hedge their carbon exposure, including a low correlation with traditional asset classes and ample market liquidity (in futures contracts), prices are driven by multiple and somewhat unpredictable factors. Moreover, these factors tend to change over time, as illustrated in the 39% decline in carbon prices in February-March 2022 while natural gas prices reached a record high.⁴⁹ Such unpredictability may become an additional source of risk for financial sector firms aiming to reduce their climate-related financial risks. The structural decrease in the supply of allowances built into the cap-and-trade mechanism may create further issues (e.g. due to margin calls or price volatility) in the long run should financial market participants increasingly rely on emissions allowances for hedging purposes.

Given these limitations, alternative approaches to carbon risk hedging are likely to develop. While they remain nascent, the development of voluntary carbon markets – where carbon offsetting mechanisms are traded – constitutes another possible avenue for future carbon risk hedging. Estimates of the size and price of voluntary markets vary greatly due to the pure bilateral (and over the counter) nature of trading. A frequently cited report⁵⁰ estimated turnover at USD 1 billion in 2021, with trading mainly in "Forestry and Land Use" credits and "Renewable Energy" credits. These markets and the instruments traded currently face some daunting issues (lack of standardisation, liquidity, cross-border fragmentation, etc.), but the Paris Agreement's objective of reaching net zero emissions by 2050 has been fuelling growing interest in these instruments.

2.4.2 Physical risk diversification and mitigation

Financial losses stemming from physical risk may be mitigated through physical protection or diversified with insurance or the use of collateralisation. In the banking sector, more than half of loans to firms are secured by financial or real estate collateral. Hence, broad-based financial and physical loan collateralisation is potentially an important instrument in the mitigation of the impact of climate-related shocks of physical risk exposures. However, if the collateral is affected by climate-related and weather events, the resulting damage affects the physical collateral and cannot limit potential losses for banks. As such, insurance instruments can significantly increase the resilience of banks and the real economy to shocks by mutualising and diversifying losses to (re-)insurance companies. The system-wide impact nevertheless depends on the loss-absorbing capacity itself and calls for an integrated approach (see Section 3).

The existence of a significant insurance protection gap in those EU countries with large banking sector exposures to physical risk events that are uncollateralised or secured by physical collateral is a particular source of concern (see ECB/ESRB, 2021; ECB 2021). Around 75% of the exposures of euro area banks to firms subject to high or increasing flood risk is uncollateralised or secured by physical collateral (Chart 18, left). This might raise concerns,

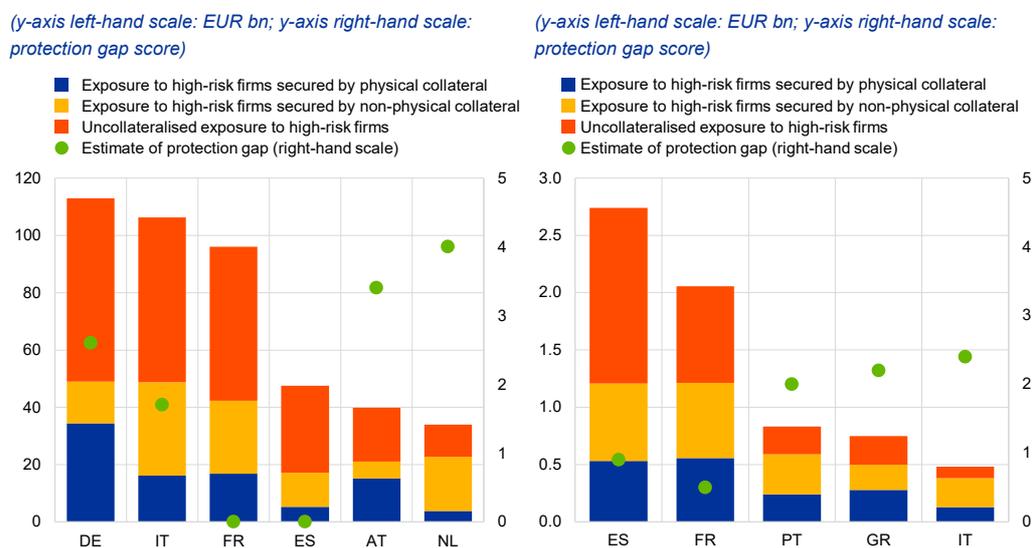
⁴⁹ Emissions allowance futures are often traded in tandem with energy commodity derivatives contracts, such as natural gas futures.

⁵⁰ See [Ecosystem Marketplace, State of the Voluntary Carbon Markets \(2021\)](#). Very low volumes in Europe are attributed to the fact that the EU ETS compliance regime stopped accepting carbon offsets.



particularly in countries with high banking exposures and an estimated medium or high-risk level in the insurance protection gap for floods. The potential loss of value for banks exposed to high-risk firms would be significant, should extreme floods intensify or affect a large proportion of these firms, and may result in reduced lending, with consequences for high-risk and lower-income borrowers and the wider macroeconomy (EIOPA, 2021). Even where insurance penetration has improved, an increasing frequency and/or severity of extreme events might affect the affordability and availability of insurance in the future (see Section 4.2). The exposure of euro area banks to firms subject to other hazards is much lower, but it is also mostly uncollateralised or secured by physical collateral (Chart 18, right).

Chart 18
Exposure of euro area banks to high-risk firms for floods (left-hand panel) and all other hazards (right-hand panel)



Sources: EIOPA pilot dashboard on insurance protection gap for natural catastrophes, AnaCredit and ECB calculations.
 Notes: Credit exposures to NFCs above €25,000 are considered; NFC location used to assign risk levels refers to the head office and the location of subsidiaries of the largest listed firms. Only NFCs domiciled in areas that are classified as high-risk or red flag are included. The country breakdown refers to the firm's domicile. The total collateral value at instrument level is capped at the value of the instrument. The protection gap of firms is proxied by the estimate of today's protection gap score of its country (0 no risk, 1 low risk, 2 low/medium risk, 3 medium/high risk, 4 high risk). Left-hand panel: flood risk. Right-hand panel: all other hazards.

As well as the insurance protection gap, there are also limitations on loan risk mitigation through collateralisation. If real estate collateral is in the same area as the firm, the losses from loan defaults and on collateral valuation could be highly correlated. In this case, the additional impact of physical risk through collateral would lead to a positive correlation between the PD and LGD of exposures. Internal analyses conducted at Banca d'Italia show that in Italy, 58% of the total amount of loans granted to corporates is secured either by collateral or by other guarantees. However, this share drops to 38% of the total amount of loans in the event of collateral destruction.



Damage functions could be a useful tool to analyse the role of collateral in mitigating climate risk. However, this would require an improvement in the granularity of the currently available data in terms of collateral localisation and the nature of the guarantees provided. Usually, credit registers explicitly identify real estate guarantees⁵¹. These are naturally exposed to physical risk. Nevertheless, personal guarantees could also be impaired if the assets of the protection provider are affected by physical risk.

⁵¹ For example, in AnaCredit the identifiers for these kind of guarantees are “Residential real estate collateral”, “Offices and commercial premises”, “Commercial real estate collateral” and “Other physical collaterals”.

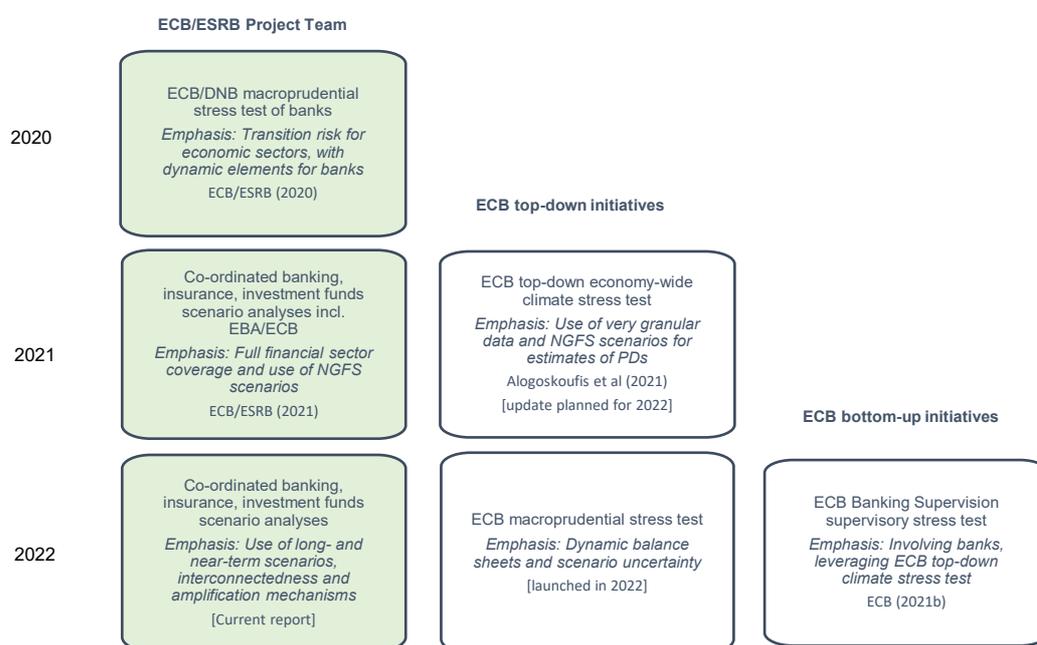


3 Climate stress and scenario analysis

3.1 Modelling climate-related risks for financial stability

Climate stress testing has evolved considerably over the last few years. Over the years, the ESRB/ECB Project Team has sought to create a platform which brings together advances in financial system-wide climate stress testing, leveraging best practices of members. Initial exploratory work in 2020 focused on transition risk at the level of economic sectors over a five-year horizon, combining a pioneering De Nederlandsche Bank pilot climate-stress test with an ECB model incorporating dynamic balance sheets and feedback loops for banks (see Figure 3). Subsequent advances in granular mapping of broader physical and transition climate risk metrics to economically relevant banking sector exposures paved the way for a far more granular firm-level climate stress test exercise in 2021 – when the Project Team benefited from advances in the ECB’s top-down stress testing of banks (which also played a prominent role in recently conducted bottom-up stress testing of ECB-supervised banks).

Figure 3
Evolution of ECB/ESRB climate stress test initiatives



Source: ECB/ESRB.

In this report, efforts have built on earlier advances to focus on a deepening and broadening of scenarios and models, as well as an increased focus on dynamics – both within and across financial entities. First, long-term scenarios have been refined, and climate risks are also



examined over shorter horizons more traditionally associated with traditional stress testing and financial decision-making (Section 3.2). Second, credit and market risk are assessed on the basis of these scenarios for an enlarged set of non-financial institutional sectors – spanning not only firms but also the relatively less explored household and government sectors – on the basis of a “horse race” of the models currently available within the ESRB membership (Section 3.3). Third, impacts on banks, insurance companies and investment funds are explored in a common way (Section 3.4), alongside an examination of the scope for dynamic adjustments of these entities (Section 3.5). Lastly, systemic amplifications and interactions across the banking, insurance and investment fund sectors are explored through the application of state-of-the-art system-wide stress testing methodologies (Section 3.6).

3.2 Climate-relevant scenarios: long versus short horizons

Long-term scenarios project how, and at what cost, a rise in global temperatures may be limited. Long-term scenarios typically have a 10 to 30-year horizon, consistent with the window commonly associated with transition policies to reduce emissions in order to comply with the Paris Agreement (Table 2). A level of policy ambition is expressed through a cap on the average increase in global temperature, the corresponding reduction in CO₂ emissions and a level of physical risk. Transition policies are captured by a representative notional carbon tax encompassing the transition costs arising from any combination of policy measures and are reflected in shadow carbon prices.⁵² Chronic physical risks are factored in through rising temperatures, precipitation and crop yields.

Notwithstanding these strengths, long-term scenarios also have some limitations, notably that they smooth out shorter-term fluctuations and can underestimate acute physical risks.

By focusing on long-term trends, they may gloss over economic and financial cycles, which can amplify the impact of climate-related shocks. The damage and financial stability implications of extreme weather events, due to their regional nature, are not comprehensively captured in macro variables, even though the frequency and intensity of extreme weather events are expected to increase over time in the absence of transition policies.⁵³ Lastly, long term scenarios are not designed to take into account regulations or restrictions that may differ between countries.

Short-term scenarios can play a complementary role in risk assessments in several ways.⁵⁴

They can illustrate how cyclical developments (such as sudden changes in commodity prices, or business and household confidence) or short-term developments (such as energy shortages) could derail or accelerate the planned and relatively smooth transition path in the long-term scenarios

⁵² Shadow carbon prices are defined as the marginal abatement cost of an incremental tonne of greenhouse gas emissions.

⁵³ As stated in the IPCC Sixth Assessment Report “human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5” (in 2014). Moreover, the report also states that “human influence has likely increased the chance of compound extreme events since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale (high confidence), fire weather in some regions of all inhabited continents (medium confidence), and compound flooding in some locations”.

⁵⁴ Short-term scenarios reflecting transition risks have been proposed by Vermeulen, et al. (2018) and the ECB/ESRB joint report (ECB/ESRB, 2020). ECB (2021) also assesses banks’ short-term vulnerabilities in a three-year disorderly transition scenario triggered by a sharp increase in the price of carbon emissions.



(harsher policy measures taken in response to acute physical risks). They can capture the impact of acute physical risk events, including those taking place at or around the same time, e.g. a summer heatwave affecting most if not all of Europe, or the risk of major river flooding and/or flash floods taking place in several countries within a short period. By offering greater flexibility, short-term scenarios can be applied to evaluate vulnerabilities to transition risk for national financial systems, especially when the mitigation effort is not uniform across jurisdictions.

Short-term scenarios also offer the added benefit of being closely aligned with traditional stress testing practices. Their horizon may be considered less hypothetical and more immediately relevant for financial institutions, decision makers and other stakeholders than long-term scenarios. They can also be more readily used to assess whether, and to what extent, the financial sector amplifies or dampens shocks.

Table 2
Application of long- versus short-term scenarios

Scenarios	Long-term scenarios	Short-term scenarios
Horizon	10-30 years	1-5 years
Transition risks	Represented by a shadow carbon price (NGFS)	Specific climate policies or events (e.g. shocks to commodity prices) may be modelled in greater detail
Physical risks	Chronic physical risk (acute physical risks may be included in the future)	Mainly acute physical risks, often with a focus on a specific extreme event
Objectives	Assessing trade-offs between climate policies and inaction Understanding structural changes	Assessing the impact of one-off, adverse events Focusing on specific details (e.g. propagation of shocks, second-round effects)

3.2.1 Building long-term scenarios

Different levels of policy ambition result in three categories of NGFS transition scenarios.⁵⁵

Orderly transition scenarios incorporate relatively low transition and physical risk. Disorderly transition scenarios feature higher transition risk, as in the delayed transition scenario, while hot-house world scenarios include little transition but higher physical risk (Table 3, Chart 19).

⁵⁵ NGFS climate scenarios provide a common framework for central banks and supervisors to integrate climate risks into financial stability monitoring. First released in June 2020 (first vintage), they have been updated and enhanced in June 2021 (second vintage) and explore both transition and physical risks.



Table 3

Three long-term NGFS scenarios

	Current policies	Net zero 2050	Delayed transition
Level of ambition			
Average increase in global temperature	More than 3°C	1.5°C	Below 2°C
The amount of CO2 emissions	Global CO2 emissions remain relatively steady until 2050	Global net zero CO2 emissions reached around 2050, with some jurisdictions, incl. the EU, achieving net zero for all greenhouse gases	Global net zero CO2 emissions achieved around 2050
Level of transition risk	Relatively low	Relatively low	High
Level of physical risks	Increases until the end of the century	Relatively low	Relatively low
Policies and innovation			
Policies	Only currently implemented policies are kept in place	Climate policy implemented immediately and increases gradually. Government revenue from carbon tax is recycled, in part to finance public investments.	Climate policy is delayed until 2030. From 2030 onwards, strong climate policies are needed to make up the delay
Innovation	Slow rate of innovation	Low-carbon electricity and electricity storage develop.	Innovation is slow until 2030, then fostered by climate policies.

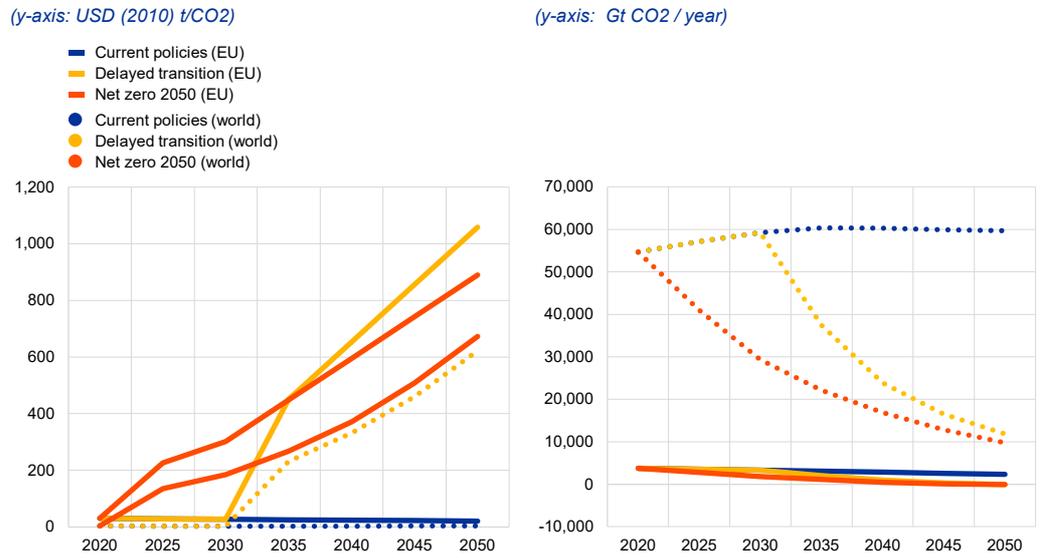
The materialisation of physical risks in the current policies scenario increasingly results in irreversible business disruptions and property damage over the next few decades. Labour productivity, agriculture, ecosystems and sea levels are significantly affected, particularly in the second half of the century.

In the net zero 2050 scenario, both physical and transition risk remain relatively low in a longer-term perspective, improving economic outlook compared with the current policies baseline (Chart 20). Relative to the latter scenario, EU GDP is 3.2% higher in 2050, rising to more than 6% higher in 2100. The gains from the early and orderly transition are even greater globally, with world GDP 13% higher in 2100 in the net zero 2050 scenario than in the current policies scenario. This reflects a relatively smaller increase in physical risk in the absence of transition in the EU compared with other locations.



Chart 19

Carbon prices in USD (left-hand panel) and GHG emissions in EU (right-hand panel)

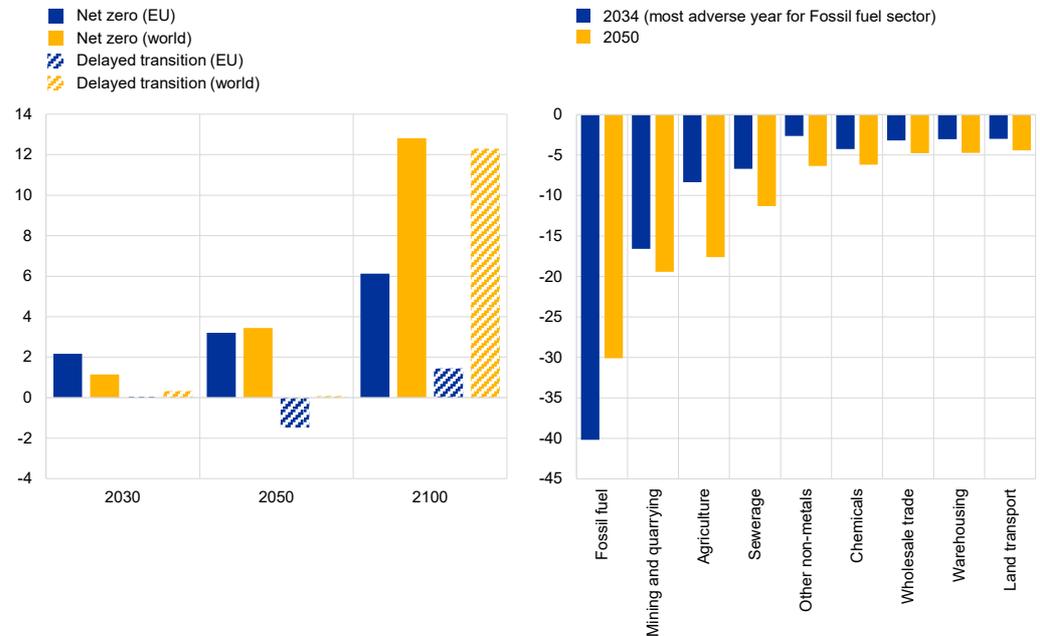


Source: NGFS Scenarios, June 2021.

Chart 20

GDP impact and sectoral value added in the delayed transition scenario (EU)

(y-axes: difference relative to current policies scenario, percentages)



Source: NGFS Scenarios, June 2021.



In the delayed transition scenario, the late phase-in of transition policy decreases the economic gains of a timely transition. The increase in carbon prices is steeper and the transition occurs in a disorderly way. Policy uncertainty leads to a higher investment premium. Firms need to adapt rapidly, resulting in more disruptions and stranded assets. Although physical risks remain relatively contained, overall GDP in the EU drops by 1.5% compared with the current policies scenario in 2050. However, a delayed transition is still preferable to no transition in the longer term: due to avoided physical damage, GDP rises more than in the current policies scenarios by 2100 (in the EU, but especially at the global level).

One practical limitation of NGFS scenarios is that they do not provide detailed information at the sector level. The sectoral model developed by the Deutsche Bundesbank disaggregates GDP shocks due to transition risk into sectoral value-added (Frankovic, 2022). The model includes 56 NACE two-digit sectors and seven regions, including the euro area, the Rest of the EU, the Rest of Europe, US, China, other developed countries and the rest of the world. It relies on input-output tables, and accounts for general equilibrium effects that would occur in the event of a rise in carbon prices, including substitution across sectors and energy sources.

Although the overall impact on the EU economy appears moderate, the results show that some sectors may be hit particularly hard. In the case of a disorderly transition, this is particularly true of most GHG-emitting sectors, primarily fossil fuel, mining and quarrying and agriculture (Chart 20, right-hand panel). The impact on sectoral value added may reach -40% in 2034 for fossil fuel producers, a few years after the delayed start of transition policies.

Box 4

NGFS Scenarios and Fit for 55

The European Commission adopted the Fit for 55 package in July 2021 (European Commission, 2021b). Fit for 55 paves the way to carbon neutrality by 2050 by means of a set of proposals to make the EU's climate, energy, land use, transport and taxation policies fit for lowering net greenhouse gas emissions by 55% by 2030, compared with 1990 levels.

The Fit for 55 package sets emissions and energy use targets that are close to the NGFS net zero 2050 scenario. In the NGFS net zero 2050 scenario released in June 2021 (European Commission, 2021b), emissions decrease by between 47% and 69%, even though it does specify climate policies and uses a shadow emission price as a proxy for climate policy intensity. The Fit for 55 package elaborates on specific policy measures, such as stricter CO₂ emission standards for vehicles and amendments to air transport regulations.

Additional scenarios have been developed in order to assess the impacts of the Fit for 55 policy package (European Commission, 2021c). The Joint Research Centre provides an **online platform** that enables the exploration of energy data in various scenarios, including the Fit for 55 MIX scenario, which achieves net 55% GHG emission reductions by 2030 compared with 1990. The Fit for 55 MIX scenario targets a share of 40% of renewables (including biomass) in the energy mix by 2030, while in the NGFS net zero 2050 scenario this share is between 36% and 47%.



3.2.2 Building short-term scenarios

Three short-term (i.e. 5-year) horizon scenarios are considered in this report (Table 4). The first short-term scenario reflects the risk of an immediate and disorderly transition with a sharp increase in carbon prices. The second short-term scenario assumes that extreme flood events take place at the EU-level in the first quarter of 2022 and are twice as damaging as the floods in 2021. Flood risk has a substantial impact on properties and may affect different asset classes (households, companies, infrastructures, public buildings). The third near-term scenario assumes that a long heatwave period would affect EU countries in the summer of 2022. Long heatwave period reduces the GDP of affected countries via a decrease in productivity, especially for outdoor sectors such as agriculture, construction and tourism.

Table 4

Three short-term scenarios

	Carbon prices	Flood risk	Heatwave risk
Risk type	Transition	Physical	Physical
Trigger	Immediate and substantial increase in carbon prices	Extreme flood in the EU in the first quarter of 2022	A long heatwave in the EU in the summer of 2022
Design	An increase in carbon prices corresponds to the front-loaded change in carbon prices in five most adverse years of the NGFS delayed transition scenario*	Total losses due to the impact of flooding on asset and properties in 2022 of €100 billion. The JRC Flood Risk Index differentiates losses across regions and countries.	Adverse country-level productivity shocks for EU countries
Additional information on calibration		Estimated direct and indirect costs of 2021 losses due to floods exceed €40 billion, with some estimates nearing €50 billion.	Country-level productivity shocks due to heatwaves from the NGFS Climate Impact Explorer, based on ISIMIP data. Selecting the higher end of the impact distribution in 2020.

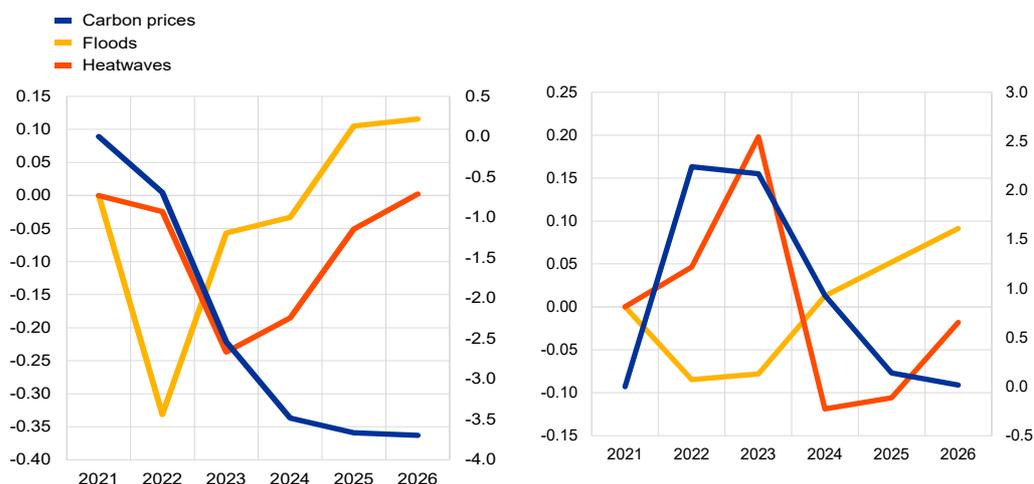
*Note: * The adverse impact of carbon price increases is partially mitigated by higher revenues raised through the carbon tax, with half of these being then recycled in the economy in the form of an income tax cut.*



Chart 21

EU GDP and euro area inflation

Left-hand side: differences in percentage points of GDP compared with the baseline, left-hand scale, carbon price scenario, right-hand scale, floods and heatwaves scenarios. Right-hand side: difference in percentage points of inflation compared with the baseline, left-hand scale, carbon price scenario, right-hand scale, floods and heatwaves scenarios.



Source: NiGEM simulations run by Banque de France staff.

Shocks reflecting the three short-term scenario narratives have been implemented in the NiGEM model.⁵⁶

In the short-term adverse transition scenario, the steep increase in carbon prices in all EU countries has an impact on GDP and inflation. EU GDP losses reach almost 4% in three to five years, as compared to the baseline⁵⁷ with no increase in carbon prices, and more than 5% in certain countries. Inflation increases temporarily after the initial shock but decreases after a few quarters along with the monetary policy response (Chart 21).

Acute physical risks appear to embed the potential for somewhat more contained GDP losses, albeit without considering amplification mechanisms or “tipping points”.

In the flood risk scenario, capital stock destruction owing to floods negatively affects GDP. The impact of floods in the short-term is, however, much lower than in the adverse transition scenario and amounts to around -0.3% in 2022. The reconstruction of buildings and plants supports growth at the end of the period (Chart 21). The impact on inflation is mild in this scenario. In the heatwave risk scenario, labour productivity shock due to heatwaves across the EU in summer 2022 results in GDP losses, mainly in 2022 and 2023, before a recovery by 2025. GDP losses range between -0.2% and -0.5%

⁵⁶ The transition scenario approach is like that of Vermeulen, et al. (2018) which applies a NiGEM model to transition shocks, and the ECB (2021) which focuses on the most adverse three-year disorderly transition in the NGFS disorderly transition scenario. For the physical risk scenarios, the approach differs from that of the ECB (2021) or Caloia and Jansen (2021) who focus on acute physical risks, such as floods with a one-year project horizon. It also differs from that of Jun et al (2021), who rely on the percentile-based analysis and describe climate stress scenarios according to decreases in the return on stranded asset portfolios.

⁵⁷ The short-term baseline is a scenario with no transition or physical risks.



between countries. The impact on inflation is mild in this scenario. Prices increase slightly in the first few years, before returning to prior levels at the end of the period.

3.3 Scenarios and financial losses

Identifying the channels through which climate-related risks affect the economy and then spill over into the financial sector is a core aspect of climate stress testing. An earlier ESRB (2021) report discusses the available methodologies, along with challenges related to data availability (e.g. firm-level data on balance sheet indicators, energy expenditures and decarbonisation plans), the adaptation of stress testing models to long-term scenarios and modelling in anticipation of significant structural changes. The substantial progress made in ESRB and Eurosystem member institutions since that time is discussed in this section.

3.3.1 Corporate sector

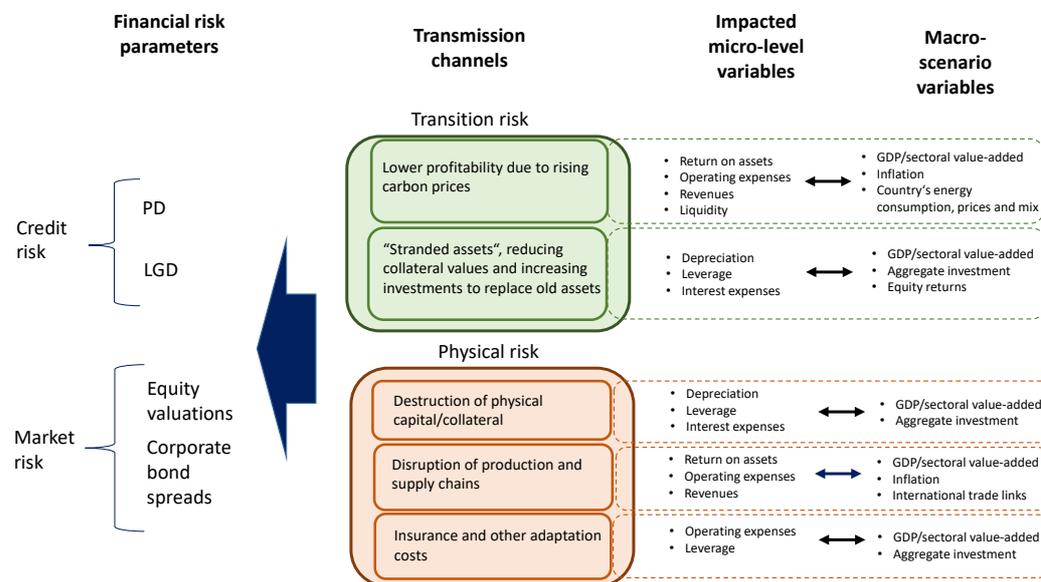
Transition risk may affect the corporate sector by affecting corporate profitability and producing “stranded assets” (Figure 4). Rising carbon prices linked to transition policies can lead to higher costs and lower profitability, thereby increasing corporate PD and reducing equity and bond valuations. Firms’ assets may unexpectedly lose their value due to sudden transition policies. Such stranded assets reduce the value of available collateral for corporate loans and increase corporate LGD.⁵⁸

The transmission channels of physical risk include the destruction of physical capital, production and supply chain disruptions and higher insurance costs. The destruction of physical capital as a result of more widespread and severe natural hazards has an impact on PD by increasing firms’ leverage and the interest expenses of financing investments in new capital stock. It should also reduce collateral value and increase LGD. Vulnerabilities to physical risk occur if production processes are disrupted. Insuring against natural hazards and their effects may become increasingly costly for the corporate sector, adding to the cost of other adaptation measures.

⁵⁸ The existing models of climate specific LGD incorporate the profitability channel, but seldom the “stranded asset” channel. They are typically derived from climate scenario variables at the macro-level (e.g. ESRB 2020).



Figure 4
Mapping of micro- and macro variables to transmission channels and financial risk parameters



3.3.1.1 Horse race of credit risk models

Leveraging existing analytical frameworks and comparing them with each other in a “horse race” provides valuable insights into various modelling techniques. Table 5 provides an overview of the high-level features of the models used at ESRB institutions for projecting climate-sensitive corporate PD. The differences in model design include the level of granularity (from sector to firm level)⁵⁹, geographical coverage (country-specific and euro area), the type of risk considered (transition or physical risk or both) and the scenario variables used to calibrate the shocks.

⁵⁹ Climate-sensitive credit risk models use either sector- or firm-level models to integrate heterogeneity in corporate sector vulnerability to climate-related risks (ESRB, 2021).



Table 5

Overview of participating models for credit risk parameters: Probability of Default

Institution	Granularity	Geographical coverage	Type of risk	Horizon	Scenario variables used
Deutsche Bundesbank	Sector	Euro area	Transition, physical	Long- and short-term	Sectoral value added (54 sectors)
Banca Națională a României	Firm	Romania	Transition	Short-term	GDP, national risk premium
ECB	Firm	Euro area	Transition, physical	Long- and short-term	GDP, inflation, unemployment, carbon price, emissions, energy consumption (by source)

All of the climate-sensitive credit risk models considered integrate heterogeneity within corporate sector vulnerability to climate-related risks. Firm-level approaches combine information on firm balance sheets, emission profiles (or implicit carbon tax as in the case of the Banca Națională a României, 2019, in Table 5) and projected acute physical risk damage (ECB, 2021⁶⁰, in Table 5). The impact of transition risk and of acute and chronic physical risk is translated into effects on firms' profitability and leverage, which are used as inputs for credit risk models that project firm-level PD. The sectoral approaches rely on sector-level GVA or other sector-level macro-financial variables which are fed into satellite models for credit risk to derive the impact on sectoral PD and LGD (Allen et al. 2020, and Bundesbank, 2021,⁶¹ in Table 5).⁶²

The ECB and Deutsche Bundesbank models suggest that, over the long-term horizon (until 2050), corporate PD are lowest in the net zero 2050 scenario (Chart 22). The models predict that corporate PD at the end of the horizon would be by around 13-20% lower than in the current policies scenario. The delayed transition scenario results in an increase in PD starting in 2030s. Subsequently, credit risk remains high until the end of the horizon for the Deutsche Bundesbank model, but subsides more rapidly than the current policies scenario in the ECB model.

⁶⁰ The results presented in this section rely on the revised and further improved methodology of Alogoskoufis et al. (2021).

⁶¹ See also Schober et al. (2021).

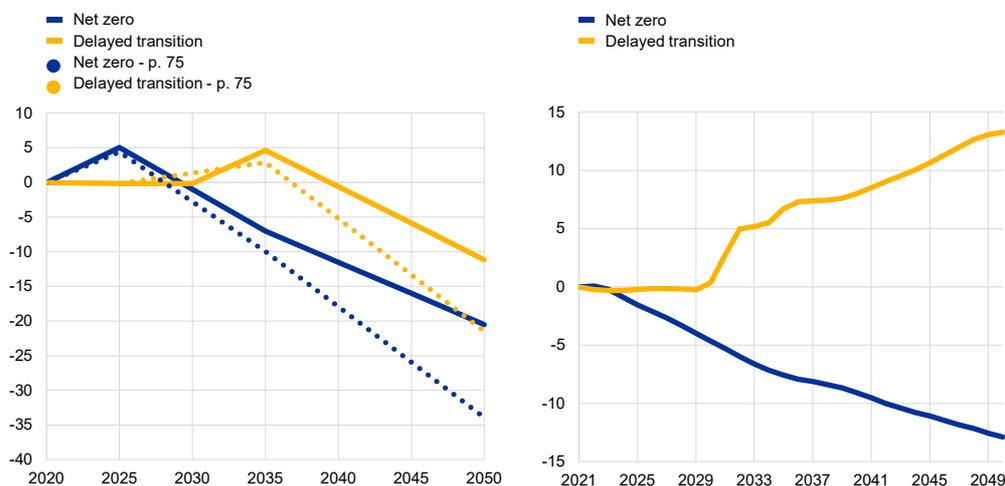
⁶² There are approaches that combine both micro- and macro-calibrations to derive climate-sensitive PD. For example, Faiella et al. (2022) propose a micro-founded climate stress test which uses firm-level administrative data to estimate the impact of carbon taxes on firms' profitability and vulnerability which is defined as negative profitability or a ratio of interest expenses relative to profits above 50%. Aiello and Angelico (2022) build on these results, by aggregating at the sector level and defining sectoral models to quantify the impact of carbon taxes on Italian banks' default rates in the short term.



Chart 22

Comparison of corporate PD models for net zero and delayed transition scenarios, ECB (left-hand side) and Deutsche Bundesbank (right-hand side)

(Y-axes: Differences compared with the current policies scenario; percentages)



Note: The PD projections refer to euro area borrowers.

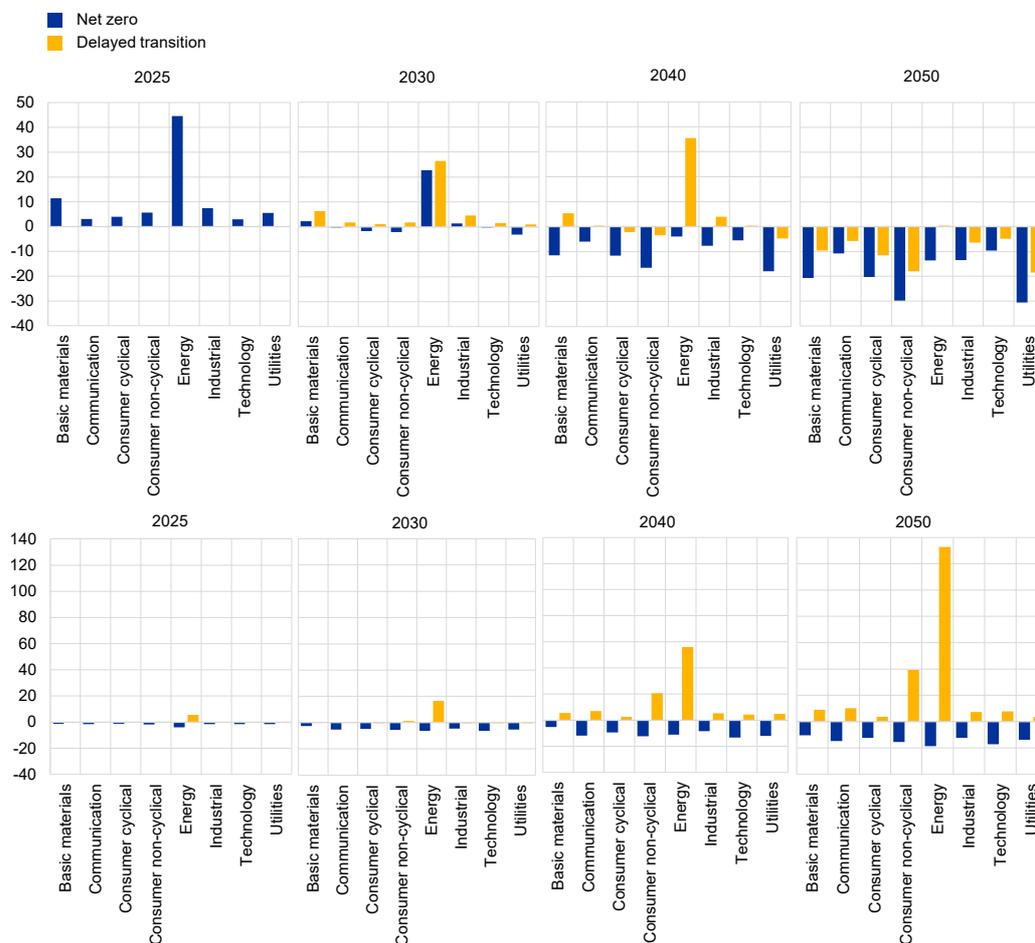
A sectoral breakdown of the results for the long-term scenarios shows a high degree of heterogeneity, which is consistent across the ECB and Deutsche Bundesbank models (Chart 23). Emission-intensive sectors, such as basic materials and energy, can experience a sharper increase in credit risk in the short-term perspective in the net zero 2050 scenario compared with the current policies scenario. However, after 2030, credit risk is expected to be significantly lower for economic sectors in the net zero 2050 compared to the current policies scenario. Consistently with the postponement of a policy action in the delayed transition scenario, an increase in credit risk in energy intensive sectors is expected at later date. It subsides until 2050, along with the relative reduction in credit risk due to the lower intensity of physical risks in the ECB model, but remains high in the Deutsche Bundesbank approach.



Chart 23

Corporate PD models for net zero and delayed transition scenarios: sectoral breakdown for ECB (upper panel) and Deutsche Bundesbank (lower panel)

(Y-axes: Differences from the current policies scenario, percentages)



Note: Results are aggregated by GICS sectors using a mapping to NACE 2-digit sectors.

Projections of corporate default rates for the short-term carbon prices scenario are compared across three models: ECB, Deutsche Bundesbank and Banca Națională a României (Chart 24).

The carbon prices scenario illustrates the accumulation of transition shocks over a relatively short time horizon and translates into marked increases in corporate PD across all models. In the ECB model, the cumulative effect of the carbon prices scenario is 7.5% over five years compared with the baseline, with no transition shocks (compared with a 5% increase over 30 years in the long-term delayed transition scenario and compared with the current policies scenario), while in the Deutsche Bundesbank model over 9% (compared to 13% in the delayed transition compared to the current policies scenario). Finally, the cumulative effect of the carbon prices scenario is as high as 27% over a five-year horizon in the Banca Națională a României model.

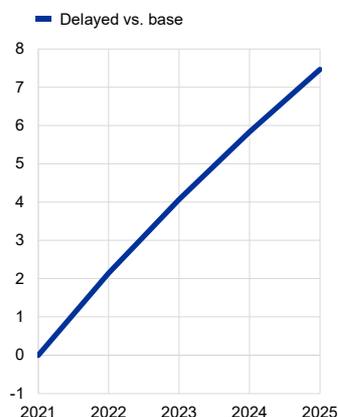


Chart 24

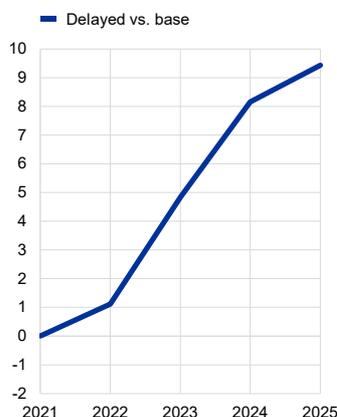
Comparison of corporate PD models for carbon prices scenario

Percentage differences from the baseline

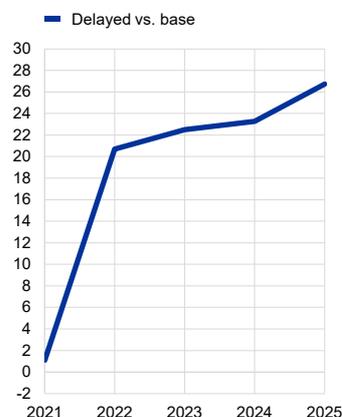
a) ECB



b) Deutsche Bundesbank



c) Banca Națională a României



Note: For ECB and Deutsche Bundesbank models, PD projections refer to euro area borrowers, the Banca Națională a României model covers Romanian borrowers only.

3.3.1.2 Horse race of models of market risk approaches

The evaluation of market risk relating to equity holdings in the financial sector requires the calculation of sector-level equity prices. The sectoral and macro-financial “suite of models” developed at the Banque de France use projected changes in sectoral GVA as input into a dividend discount model, which projects variations in sector-level equity prices (Table 6).⁶³ The ECB methodology breaks down aggregate country-level equity prices according to sector using weights calculated from firm-level PD estimates. Alternative models perform the breakdown of aggregate equity prices to sector-level indicators by means of transition vulnerability factors (Vermeulen et al. 2019, ESRB 2020 pilot exercise) or based on model-generated changes in sectoral value added (Deutsche Bundesbank, 2021).

⁶³ In a similar manner, EIOPA (2021a) and the ECB/ESRB (2021) scenario-conditional changes in production levels, and later companies’ revenues and expenses from the PACTA tool, which then affect companies’ market valuations via discounted future dividend flows.



Table 6

Overview of participating models for market risk parameters

Institution	Model type	Approach	Granularity	Geographical coverage	Type of risk	Scenario variables used
Banque de France	Equity prices	Dividend discount model	Sector	France, euro area, United States, United Kingdom	Transition, physical	Sectoral value added (from input-output model)
ECB I	Equity prices	Weight of NGFS equity price changes by NACE sector average PDs	Firm, country	Worldwide firms	Transition, physical	Equity prices
Banque de France	Corporate credit spreads (five year)	Calibrated Merton's formula and Gaussian VaR-based projections	Sector	France, euro area, United States, Japan	Transition, physical	GDP growth, inflation rate
ECB I	Corporate bond prices	Sensitivity coefficient of spreads to PD using an econometric model	Firm	Worldwide firms	Transition, physical	Stressed PD
ECB II	Corporate bond prices	DNB approach (one-to-one) relationship between change in spreads and change in PD	Firm	Worldwide firms	Transition, physical	Stressed PD

Models linking corporate bond prices to climate scenario variables allow the calculation of market losses on corporate bond holdings.

Banque de France derives corporate credit spreads⁶⁴ from a Gaussian VaR including macroeconomic variables and the term structure of sovereign yields.⁶⁵ In contrast, the ECB calculates corporate bond price changes based on firm-level PD for non-financial corporates.⁶⁶ Other approaches to estimating changes in corporate bond prices apply rating transition matrices, accounting for the carbon intensity of the bond issuer's sector using transition vulnerability factors (Vermeulen et al., 2019; ESRB, 2020). The Deutsche

⁶⁴ The data set of corporate credit spreads is obtained by converting historical default probabilities provided by the **Risk Management Institute of the National University of Singapore** into associated credit spreads adopting a calibrated Merton (1974) and Black and Cox (1976) formula. See: Allen (2020).

⁶⁵ It is important to observe that, from the projections of corporate credit spreads and sovereign yields of the same country, we can easily obtain associated projections of corporate yields.

⁶⁶ ECB stress testing framework uses a two-step procedure. First, a sensitivity of bond spreads to firms' PDs is estimated using a large panel regression of individual corporate bond spreads on the median of the expected default frequency as reported by Moody's (EDF 50), bond specific ratings, country and sector dummy variables, and several bond-specific controls following De Santis (2018) and Gilchrist and Zakrajšek (2012). Second, bond prices are computed from bond spreads using a duration equation.

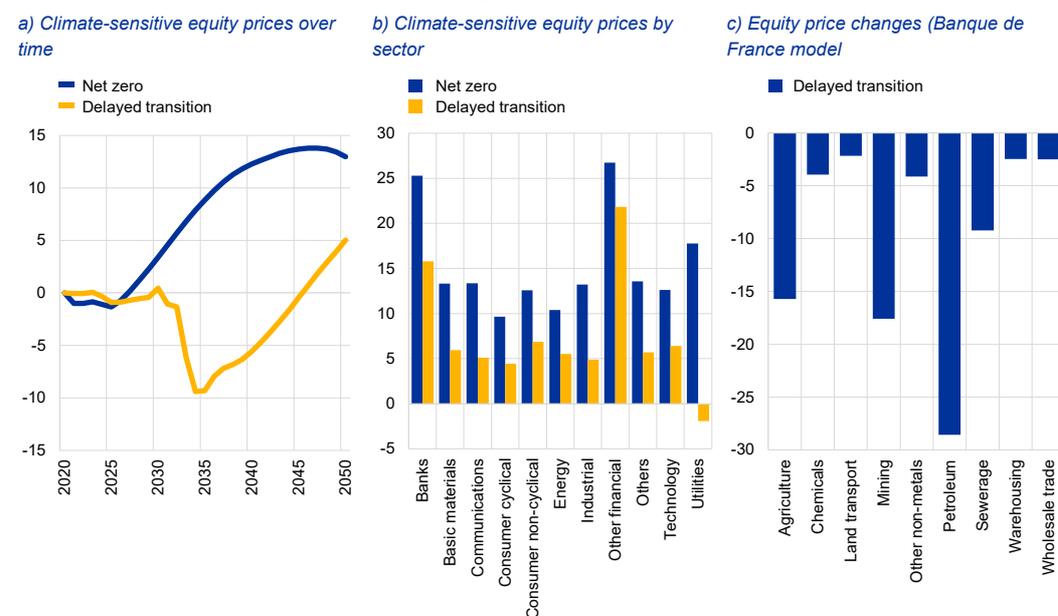


Bundesbank uses the combined historical distributions of stock and corporate bond indices and their empirical relationship.⁶⁷

A timely introduction of climate policy triggers the revision of market expectations, resulting in an increase in equity prices in the medium term. The prompt and proper climate policies in the net zero 2050 scenarios translate into a strengthening of equity prices just a few years after their inception. In contrast, the delayed and potentially disruptive introduction of policies in the delayed transition scenario results in a sharp contraction in equity prices that may persist until the end of the horizon (Banque de France model, right-hand side panel of Chart 25) or is reversed only after 2045 (ECB model, left panel of Chart 25). The gains in equity values in the net zero scenario are most pronounced for the financial sector, followed by the utilities sector (middle panel of Chart 25).

Chart 25
Climate policy effects on equity prices

(Y-axes: Differences relative to current policies; percentages)



Source: Banque de France and ECB.
Note: Middle and last panel measured at end-2050.

Well-timed climate policies also result in higher corporate bond valuations in the medium-term. In the net zero 2050 scenario, the initial drop in the value of corporate bonds is relatively short-lived and more than offset in around a decade, with corporate bonds being over 0.4% higher than in the current policies scenario in 2050 (Chart 26). In the delayed transition scenario, while the initial drop in bond valuations is prevented, the later reduction in bond prices is deeper and longer

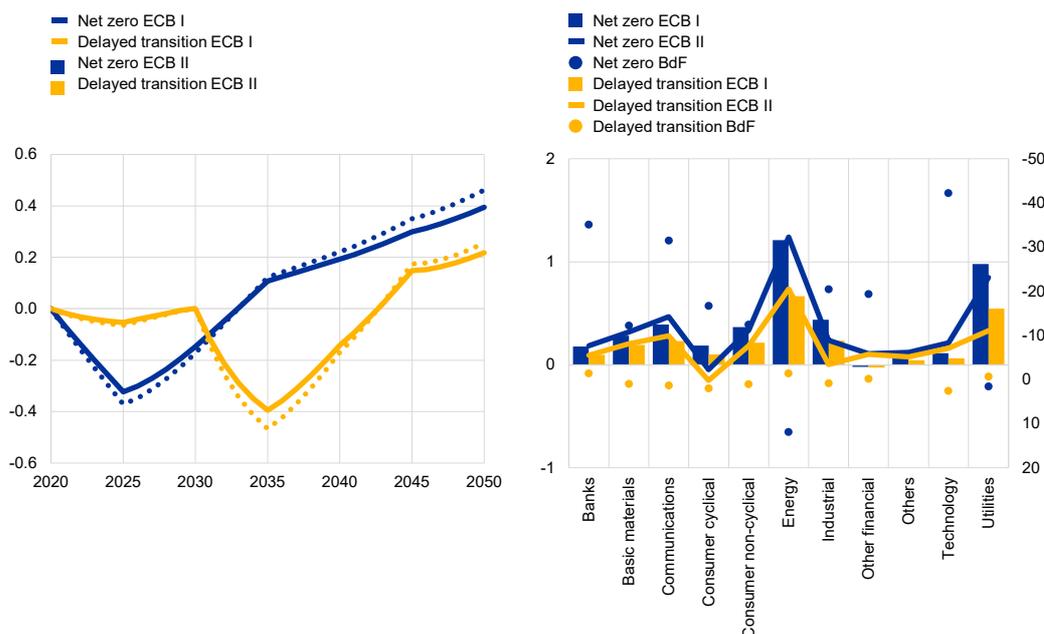
⁶⁷ The model is calibrated based on historical equity and CDS price data for Germany and other geographies. For projecting the scenario horizon, NiGEM equity prices are mapped to the empirical relationship between both asset classes. See: Bundesbank (2021) and Etzel et al. (2021).



lasting than in the net zero 2050 scenario. The sectors with highest increases in bond valuation (for both ECB models) are energy and utilities, while the sectors with the biggest narrowing of bond spreads (along with the Banque de France model) are banks, communication and technology.

Chart 26
Climate-sensitive corporate bond prices over time (left-hand side) and bond prices or bond spreads by sector (right-hand side)

(Y-axes: difference to current policies; percentage. Left-hand side: bond prices, right-hand side bond spreads.)



Note: Right-hand side: measured at end 2050. For the ECB models, bond prices, and for Banque de France model, corporate bond spreads.

3.3.2 Households

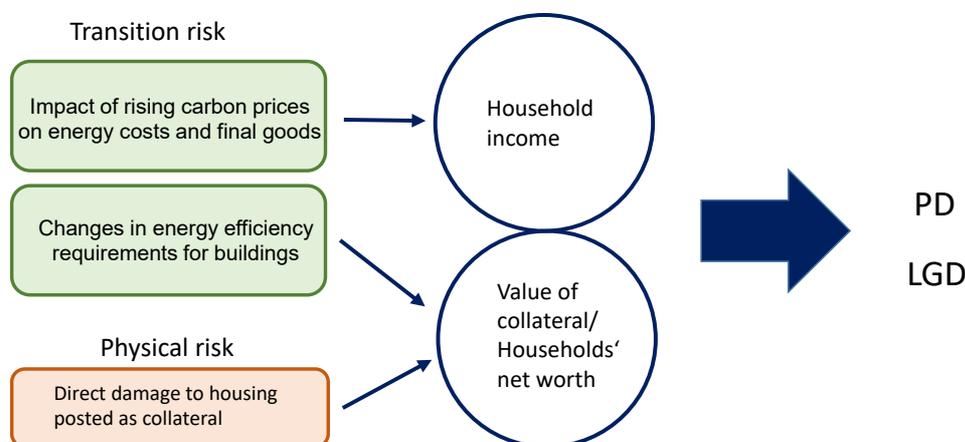
Households may be exposed to transition risk through the positive relationship between rising carbon prices and energy costs, which account for a large share of households' expenditure. Higher energy prices also affect the prices of final goods, further reducing households' disposable income. Moreover, changes in energy efficiency requirements for buildings may adversely impact the net worth of homeowners and their collateral, as buildings with lower efficiency standards can only be sold at a discount due to the large volume of investment required.

Physical risk may materialise because of direct damage to housing posted as collateral.

Spillovers into the financial sector occur via the adverse impact of climate-related risks on household income and the value of collateral, which in turn are significant determinants of PD and LGD for loans to households (Figure 5). In addition to the effect on financial risk parameters, climate-related risks may also reduce the access of households to financing due to lower net worth.



Figure 5
Impact of climate-related risks on households' PD and LGD



Despite the importance of households in the loan portfolios of banks, climate-related stress testing methodologies for households are still under-represented. Faiella et al. (2022)

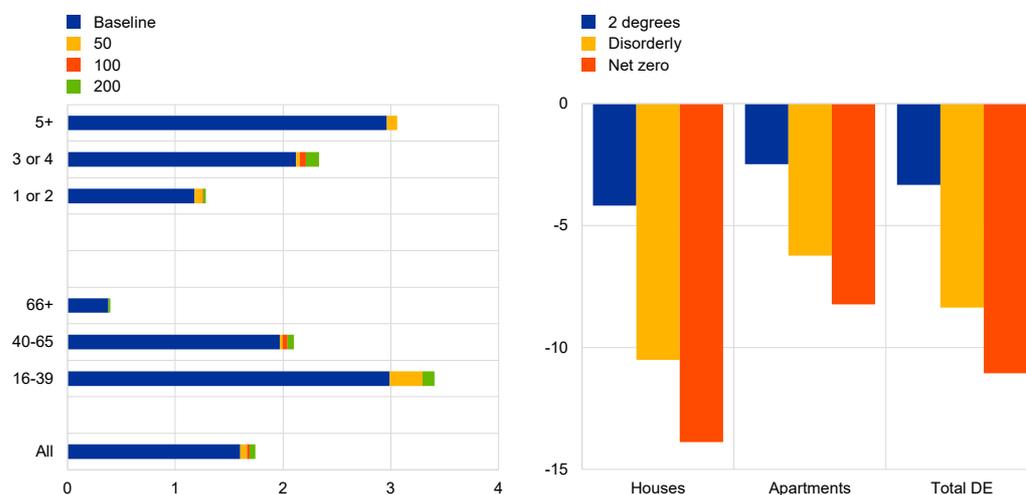
calculate the proportion of financially vulnerable households, i.e. households whose debt is at risk of defaulting, following an increase in carbon taxes (Chart 27). They first simulate the impact of carbon taxes on household income, relying on estimates for the energy demand elasticity of Italian households. The effect on household income is then translated into shifts in the proportion of financially vulnerable households, which provides an indication for the risk of higher carbon prices on banks' household loan portfolio.

Changes in property valuations could result from rising energy prices and carbon taxes.

Due to their importance as collateral, changes in residential real estate valuations directly affect LGD. By combining micro-level data on residential real estate with NGFS scenarios, Ter Steege and Vogel (2021) estimate how future developments in energy prices may affect property valuations. The effects of energy prices on valuations are assumed to be heterogeneous, depending on a building's energy efficiency level: with all else being equal, high energy consumption buildings sell at a discount due to higher heating costs and are more adversely affected by rising energy prices. Building on micro data, price discount estimates across energy efficiency levels are derived for projected energy prices under different scenarios (Chart 28, right-hand side). In principle, the results may be mapped to banks' household loan portfolios in future analyses to calculate the expected impacts on LGD.

Chart 27

Proportion of vulnerable Italian households under different carbon price shocks (€50, €100 and €200) and energy price impacts on housing price discounts in Germany across NGFS scenarios



Note: The chart to the left presents results for the heterogeneity by age of the reference person and household size. The chart to the right shows aggregate discounts in housing prices relative to the current policies scenario.

Methodological frameworks analysing the vulnerability of households and corresponding loan portfolios to physical risks are still lacking.

One major obstacle for the design of such a framework is that many supervisory authorities do not have granular loan exposure data for households due to data protection laws. This precludes the mapping of borrower-level geographical location to physical risk scores, which is necessary to infer potential losses for the banking sector.

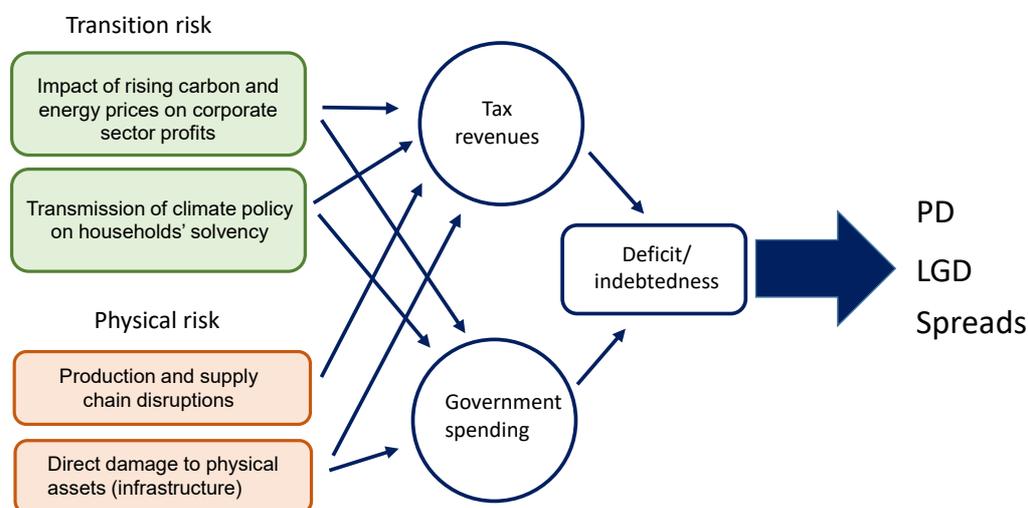
3.3.3 Sovereigns

Sovereigns are affected by transition and physical risk via the impact on tax revenues and government spending, which influence PD, LGD and credit spreads (Figure 6).

Changes in energy prices related to transition risks affect corporate sector profits and household solvency. As a result, there is an increase or decrease in the tax revenues that the sovereign issuer collects from firms operating in the energy and other related sectors and households. Transition risks also affect government spending due to greater public investment or subsidies supporting new technologies. Physical risk transmits to government finances and net assets via disruptions in production processes and direct damages to public infrastructure.



Figure 6
Impact of climate-related risks on sovereigns



3.3.3.1 Horse race of models for sovereign risk models

One way to map climate risks into sovereign-specific financial risk indicators such as bond prices is to leverage directly on NiGEM variables for calibration. For example, Deutsche Bundesbank (2021) relies on the paths of the government premium in NiGEM to infer changes in sovereign bond prices.⁶⁸ Similarly, the ESRB (2020) uses long-term interest rates (government bond yields) from NiGEM to model sovereign bond price dynamics in the climate-related scenario analysis.

A structural approach can be taken to model the impact of climate risks on sovereign PD.

Battiston and Monasterolo (2019, 2020) pioneered one such approach, which is further explored by EIOPA (2020) and the ESCB Workstream on Climate Stress Testing (Table 7). In the approach, different climate policies affect the sales of the energy-producing sectors⁶⁹ and the country's net fiscal assets in proportion to the contribution of these sectors to country GVA. There is a corresponding decrease (increase) in tax revenues. The climate-shock-induced change in net fiscal assets determines a distance to default and sovereign PD, based on Mertonian-type setup where a government sovereign defaults when the value of its assets falls below the value of its liabilities.⁷⁰

⁶⁸ The limitations of NGFS scenarios include inconsistencies in the modelling of euro area interest rate dynamics provided in NiGEM. For example, it can be observed that NiGEM predicts a convergence in long-term nominal interest rates, a rather unlikely path given the differences in debt levels and primary budgets in the euro area. At the same time, inflation differentials can be high and sustained for decades, which may not be plausible in a common market and currency union.

⁶⁹ For non-CPRS it is assumed that output remains constant over the scenario horizon.

⁷⁰ The estimated impact on sovereign PD is hence based on GVA-weighted CPRS energy output changes and an assumption of elasticity of a country's profitability with respect to sectoral market shares. For non-CPRS it is assumed that output remains constant over the scenario horizon. Rating implied PDs or market-implied PDs can be used as a starting point.



Climate-change-sensitive sovereign LGD are then linked to sovereign PD and relevant macro-financial variables. The Tobit regression model uses an implicit lag structure of the variables on the right-hand side to account for autoregression and the highly correlated nature of finance and macro variables (Table 7).

Table 7

Overview of participating models

Institution	Model type	Granularity	Geographical coverage	Type of risk	Scenario variables used
ESCB Workstream on Climate Stress Testing	Sovereign PD	Country	Euro area ⁷¹	Transition	Primary and secondary energy consumption by source, final energy by sector, land cover by type, long-term interest rates, exchange rate, GDP, unemployment rate, inflation rate
	Sovereign LGD	Country	Euro area ⁷²	Transition	Real GDP growth, exchange rate, inflation rate, unemployment rate, and long-term interest rate

The findings of the scenario analysis show that the Net Zero 2050 scenario may transitionally though moderately elevate sovereign risk, yet the level of sovereign risk from 2045 is markedly lower than in the Current Policy scenario (Chart 28). The delayed transition scenario triggers a sharp increase in sovereign PD and LGD in the euro zone starting from 2030. The PD and LGD tipping points in the euro area after 2035 are primarily driven by decreases in electricity and gases utilisation in the buildings sector and cutting back of liquid usage in the transportation sector. In the delayed transition scenario, the level of sovereign risk is significantly higher than in the net zero scenario, including at the end of the horizon.

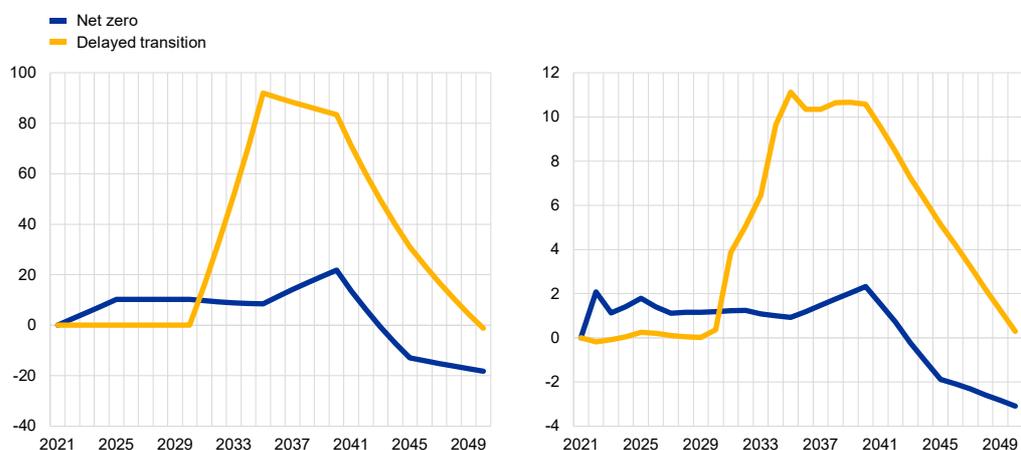
⁷¹ The GDP-weighted average of Germany, France, Italy and Spain has been used.

⁷² See footnote above.



Chart 28
Sovereign PD and LGD (euro area)

Y-axes: differences to current policies, percentages.



Notes: Euro area aggregate based on initial GDP-weighted PD of Germany, France, Italy and Spain. As the NGFS sectoral energy outputs do not integrate physical damage (at least not sufficiently) at the current stage, the results show only the effects of transition risk (REMIND-MAGPIE 2.1-4.2 without physical risk). PD modelling employs a sectoral energy output change approach. LGD modelling was derived using regressions considering sovereign PD and, macroeconomic and financial indicators.

3.4 Impact on financial institutions

Three stress test frameworks - the ECB economy-wide climate stress test, the EIOPA climate stress test and the ESMA stress test - are used to measure the impact of transition and physical risk on the expected losses of financial institutions (Table 8). For the banking sector, the scenario analysis quantifies the impact of climate risks on banks' credit risk. In each climate scenario, the total losses of banks in a given period are derived by adding up corporate loan-specific expected losses, calculated by applying the loan-specific PD (see section 1.2.1.2) and LGD.



Table 8

Overview of scenario analysis

	Banking sector	Insurance sector	Investment funds
Long-term scenarios	Current policies (baseline), net zero, delayed transition		
Short-term scenarios	Carbon prices, flood, heat wave		
Sample	~2,300 banks (monetary financial institutions residing in the euro area with credit exposures above €25,000), 19 geographical areas	1821 EU/EEA insurers	10,806 funds
Items under stress	Loans to corporate sector (notional outstanding amounts in 2020)	Equities and corporate bonds	Equities (€ 9 trillion of assets, as of March 2022)
Value of items under stress over time	Constant	Constant	Compounding (the value of an exposure changes over time along with compounded rate of return)
Risk channels	Credit risk	Market risk	Market risk
Coverage of overall exposures	27% of assets to non-financial companies	78% of equities and corporate bonds	68% of fund assets
Coverage of the overall sector	20% of total banking sector assets	27% of insurers' assets	~50% of EU investment fund net assets
Source of information on balance sheets	AnaCredit, SUBA	Solvency II QRTs, EIOPA	Morningstar
Other data	Orbis, Eikon, Bloomberg, iBach, Urgentem, Four Twenty Seven, NGFS	Solvency II QRTs, EIOPA	Refinitiv
References	ECB economy-wide climate stress test (ECB 2021)		Amzallag (2021)

For the insurance sector, the scenario analysis quantifies the impact of climate risks on insurers' holdings of equities and corporate bonds. Changes in the value of equities by sector and region are calculated by applying the corresponding price shocks for equities derived from Banque de France's "suite of models" (see Section 3.2.1.3). Changes in the value of corporate bonds by sector and region are calculated using the duration approach.

For the investment fund sector, climate risk affects the direct and indirect equity holdings of European investment funds. Indirect equity exposures arise due to funds' holdings in other funds. Around 50% of 10,806 investment funds in the sample are UCITS and 75% are domiciled in the European Economic Area (EEA30). Equities are the largest asset class held by investment funds in the sample (53%), followed by investments in other investment funds (15%), government bonds (12%) and corporate bonds (11%). Changes in the value of equities by sector and region are calculated as for the insurance sector.



3.4.1 Long-term scenarios

A timely and orderly transition to net zero emissions in 2050 would markedly reduce the credit losses of banks compared with the current policies scenario.

For the banking sector, the transition is initially reflected in subtly higher credit risk losses which at most are higher in 2030 by less than 0.1 per cent of loan value, or by 14% compared to the current policies scenario (Chart 29). However, by 2050, expected losses are lower by 0.2% of asset value, or 27%, as compared to the current policies scenario, signifying the benefits of a timely decrease in future physical risks.

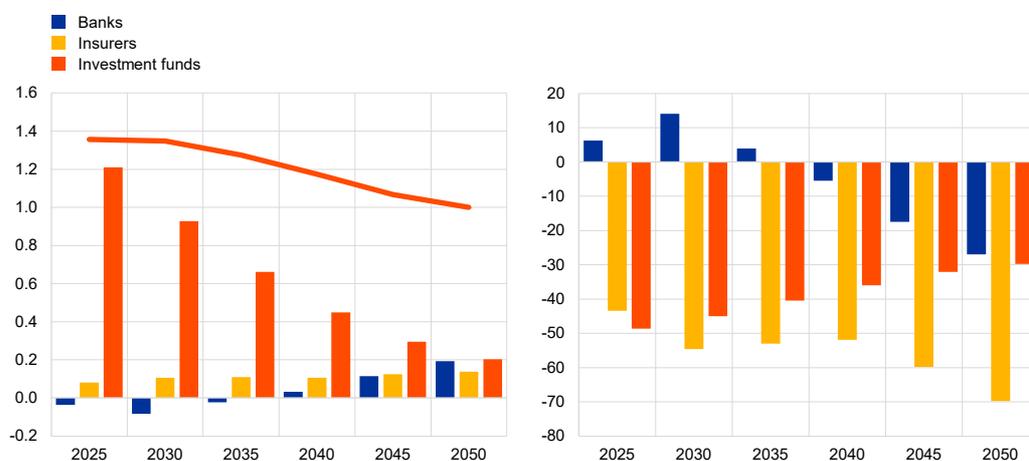
Insurers and investment funds benefit from the green transition immediately, experiencing a sharp reduction in market risk losses due to the favourable revaluation of their asset holdings

The impact of favourable revaluation of assets is particularly pronounced for equity holdings, which explains the relatively high positive difference between the losses of investment funds in the net zero 2050 scenario and their losses in the current policy scenario losses, amounting to 1.2%-1.4% of asset value, or 49% of current policy scenario losses as measured in 2025. Market risk losses of insurers go down by 0.1% of asset value (jointly equity and corporate bonds) or by 43% of the current policy scenario losses. The early reduction in insurers' and investment funds' market risk, compared with later decrease in the banks' credit risk losses, reflects the assumed forward-looking pricing of equities and bonds.

Chart 29

Evolution of expected losses in the net zero 2050 scenario

(Y-axis: Left-hand panel: percentage difference of stress tested assets compared with the current policies scenario of the same year. Right-hand panel: in percent of losses in the current policies scenario of the same year)



Sources: ECB, EIOPA, ESMA.

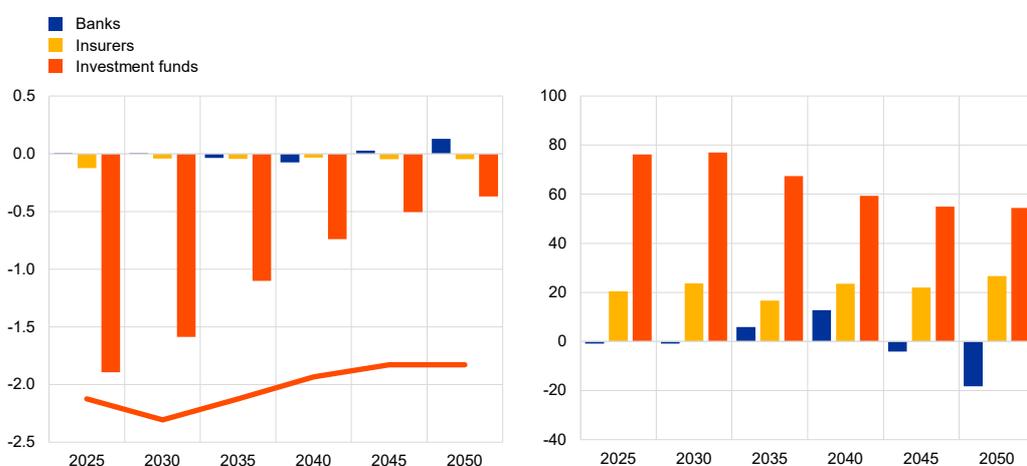
Note: LHS panel: For the banking sector bars reflect the difference in the expected credit risk losses as a percentage of initial loan values between the reference and the Current Policy scenarios. For insurers and investment funds the bars represent the analogous relative differences in market risk losses in percentage of initial asset values (equities and bonds for insurers, and equities for investment funds). The red line represents the cumulative losses of investment funds accounting for dynamic changes in equity values over time in percentage of equities measured in the reference period. Right-hand panel: expected losses in the net zero scenario compared with losses in the current policies scenario (a negative number implies a reduction in losses, and a positive number an increase in losses). The differences in methodologies of evaluating losses for the three sectors are discussed in Table 8.



Delaying and compressing the green transition, as in the delayed transition scenario, sharply limits the reduction in medium term losses of banks, insurers and investment funds present in the net zero 2050 scenario (Chart 30). Although credit risk losses increase only moderately in the short term (by 0.1% of loan value or by 13%), the positive long-term effect of transition on credit losses is also weaker than in the net zero scenario, amounting to 0.1% of loan value or 15% compared with the current policies scenario. The risks of disorderly transition are likewise pronounced for insurers and investment funds. Just as in the net zero scenario, markets quickly discount the impact of disorderly transition on the economy, and insurers and investment funds experience strong valuation losses already in 2025. These amount to under 0.1% of asset value or 20% of losses in the current policies scenario for the insurance sector, and to 1.9-2.1% or 76% for the investment fund sector. The losses of insurers and investment funds are higher compared to the Current Policy scenario until the end of the horizon (though they decrease over time at least for investment funds) reflecting the inherent assumption that the ultimate reduction in physical risks tied to late implementation of transition policies, emerges beyond the horizon of the analysis, and asset prices only to a limited degree discount the future reduction in physical risks (especially compared to the Net Zero 2050 scenario).

Chart 30
Evolution of expected losses in the delayed transition scenario

(Y-axis: Left-hand panel: difference in % of stress tested assets compared with the current policies scenario of the same year. Right-hand panel % of relative losses in the current policies scenario of the same year)



Sources: ECB, EIOPA, ESMA.

Note: Left-hand panel: for the banking sector bars reflect the difference in the expected credit risk losses as a percentage of initial loan values between the reference and the Current Policy scenarios. For insurers and investment funds bars represent the analogous relative differences in market risk losses as a percentage of initial asset values (equities and bonds for insurers, and equities for investment funds). The red line represents losses of investment funds accounting for dynamic changes in equity values over time in percentage of equities measured in the reference period. Right-hand panel: expected losses in the delayed transition compared to losses in the current policies scenario (a negative number implies a reduction in losses, and a positive number an increase in losses). The differences in methodologies of evaluating losses for the three sectors are discussed in Table 8.

There is substantial heterogeneity in the vulnerability of economic sectors and financial system losses on related exposures to transition and physical risk. In the net zero scenario,

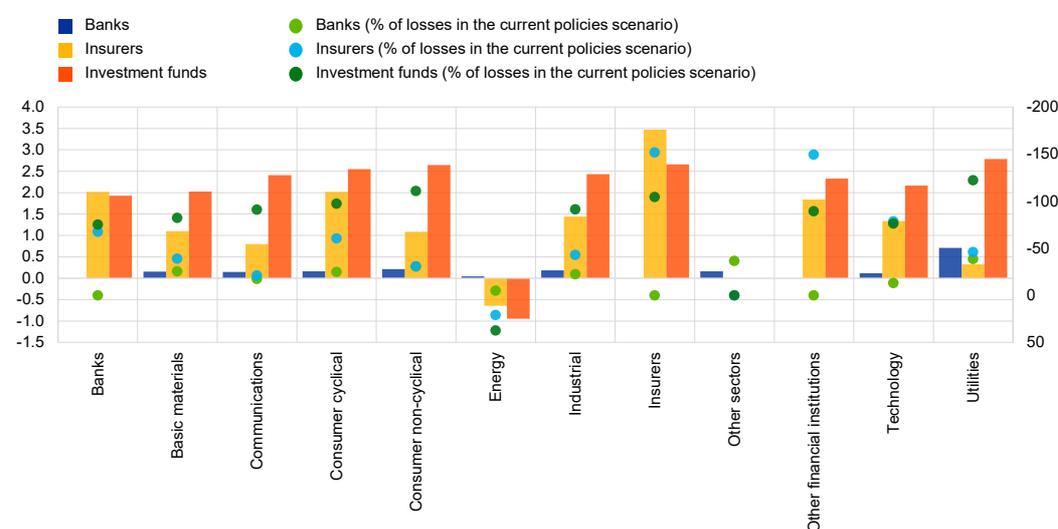


there is an increase in the expected market risk losses of insurers and investment funds for the energy sector in 2050 (the credit risk losses of banks for the energy sector decrease very subtly in the same timeframe). However, for most other sectors, the expected losses in the net zero scenario decrease substantially compared with the current policies scenario, reflecting the positive effects of containing an increase in physical risk intensity. The expected losses on exposures to non-energy sectors go down, on average, by close to 30% in the banking sector, 60% in the insurance sector and 90% for investment funds (Chart 31).

Chart 31

Expected losses in the net zero 2050 scenario in 2050, by sector

(Y-axis: Left-hand scale: percentage difference of stress tested assets compared with the current policies scenario of the same year. Right-hand scale: percentage losses in the current policies scenario of the same year.)



Sources: ECB, EIOPA, ESMA.

In the delayed transition scenario, the decrease in losses on exposures to most of the sectors is significantly lower, or turns into an increase, compared with the net zero 2050 scenario (Chart 32).

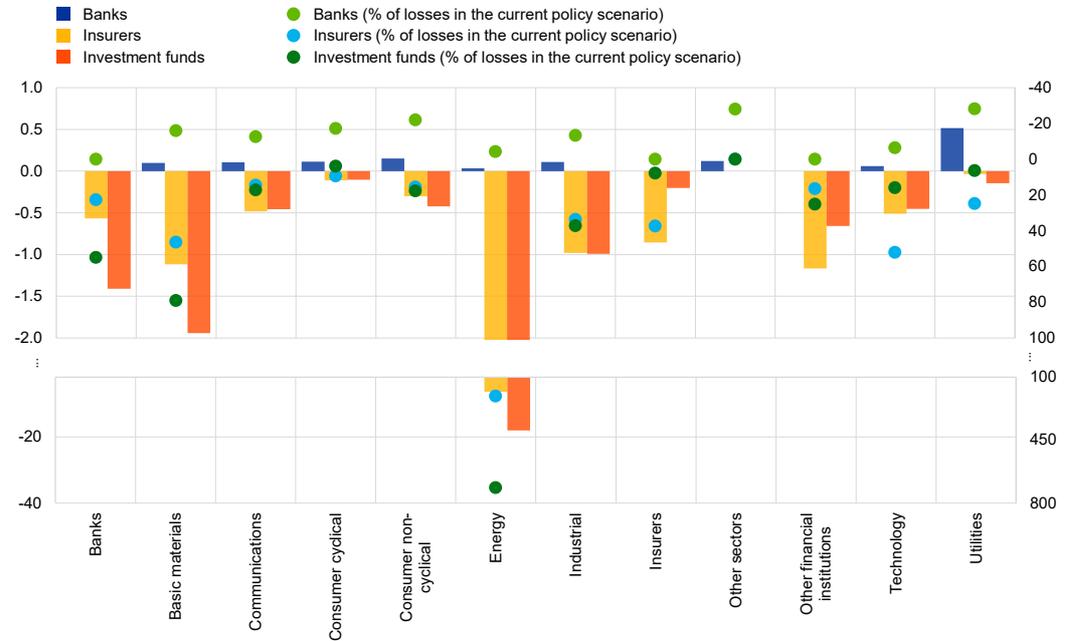
The expected valuation losses on energy sector assets for investment funds are 18% of the asset value higher than in the current policies scenario (and are seven times higher than the losses in the net zero 2050 scenario), and 6% for insurers (one and a half times higher). The valuation losses of insurers and investment funds on non-energy sector exposures increase less sharply compared with the current policies scenario, but nevertheless contrast with their clear decrease in the net zero 2050 scenario. Only in the banking sector does the delayed transition bring about some decrease in credit losses compared with the current policies, again before the end of the horizon and for several economic sectors.



Chart 32

Expected losses in the delayed transition scenario in 2050, by sector

(Y-axis: Left-hand scale: percentage difference of stress tested assets compared with the current policies scenario of the same year. Right-hand scale: percentage losses in the current policies scenario of the same year.)



Sources: ECB, EIOPA, ESMA.

3.4.2 Short-term scenarios

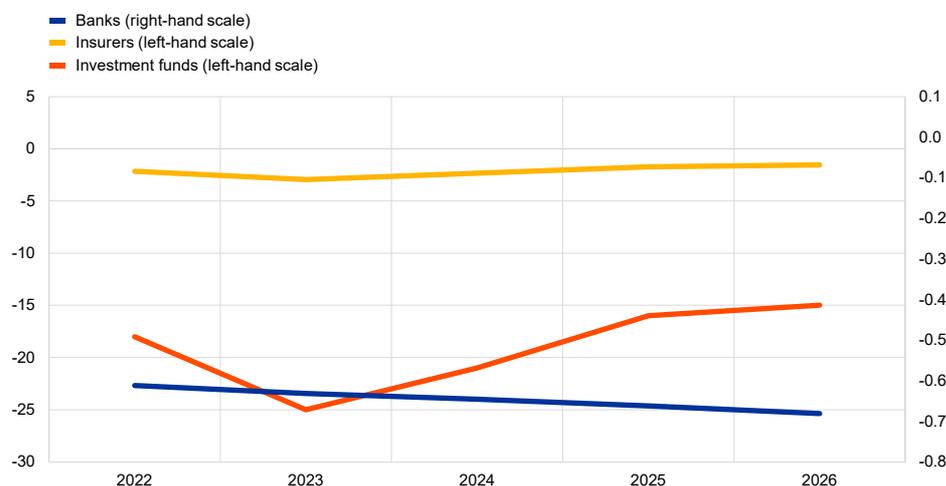
The carbon prices scenario features a concentration of transition risks which results in heavy losses for all financial institutions. Credit losses in the banking sector are around seven times larger (0.7% of outstanding corporate loans, Chart 33) than the peak losses in the delayed transition as compared to current policy scenario. The market losses of insurers amount to 3% and those of investment funds to 25% of the relevant assets in the second transition year, again surpassing more than ten-fold the losses of these institutions in the delayed transition scenario.



Chart 33

Evolution of expected losses in the carbon prices scenario

(Y-axes: percentage difference compared with the baseline in the same year. Insurers and investment funds left-hand scale, banks right-hand scale.)



Sources: ECB, EIOPA, ESMA.

Financial system losses in scenarios featuring floods or heatwaves are very low, with physical risks short-term scenarios falling short of expectations that would provide more conservative estimates of financial losses than hot-house long-term scenarios. There is an increase in expected losses in years following Europe-wide floods; however, there are very contained in terms of magnitude (0.4 basis points of corporate loans for banks, and 5 basis points of insurers' equity and bond holdings value for insurers) in the first year of the scenario (Chart 34, left- side and centre panels). The peak losses of the heatwave scenario fall in the second year of the horizon, amounting to a mere 0.3 basis points for banks, and 20 bp for insurers. Only for investment funds, valuation losses amount to a substantial, though temporary, 2% of equity holdings in the second scenario year (Chart 34, right-hand panel).

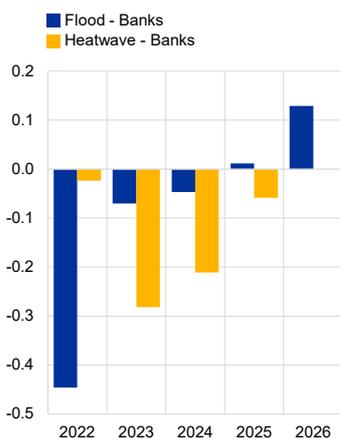


Chart 34

Evolution of expected losses in floods and heat waves scenarios

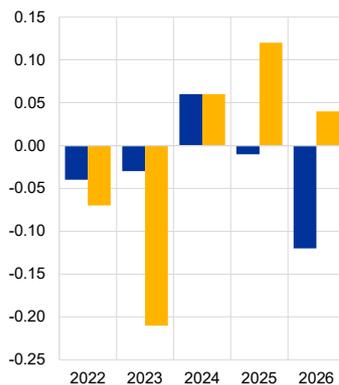
a) Evolution of expected losses for banks

(y-axis: difference of stress tested assets compared to the baseline in the same year, basis points)



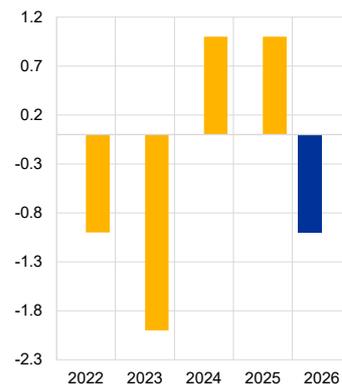
b) Evolution of expected losses for insurers

(y-axis: difference of stress tested assets compared to the baseline in the same year, percentage)



c) Evolution of expected losses for investment funds

Evolution of expected losses for investment funds



Sources: ECB, EIOPA, ESMA.

3.5 Beyond the constant balance sheet

The most recent climate risk pilot exercises have used a static balance sheet assumption⁷³.

The assumption insures against underestimating future potential financial impacts. In addition, the constant balance sheet assumption considerably limits the already high computation burden, the amount of complexity and the resource intensive nature of these exercises. Last, this approximation may be acceptable over a short stress test time horizon.

With longer time horizons, as it is often the case with climate-relevant scenarios, advantages from applying a dynamic balance sheet perspective increase. A dynamic balance sheet approach can reflect how financial entities seek to control, reduce and/or mitigate the size of their potential losses, mitigating the risk of overestimating financial losses, and can take account of efforts to transition towards a lower carbon economy by non-financial sectors (Box 5).

The implementation of a dynamic balance sheet in a climate stress test has been explored by the French Prudential Supervision and Resolution Authority (Autorité de contrôle

⁷³ Fewer than one third of the growing number of exercises use assumptions to partly reflect the dynamic nature of financial institutions' balance sheets, and therefore their ability to manage and reduce their climate-related financial risks.



prudentiel et de résolution – ACPR). The ACPR pilot exercise⁷⁴ required banks and insurers to apply the constant balance sheet assumption for horizons from 2020 to 2025 and a dynamic balance sheet perspective from 2025 to 2050. Banks could adapt their banking books through non-renewal of loans, loan sales, demanding higher collateral, or re-pricing lending rates. They could also adjust their trading books by selling or buying assets. Insurers could modify premiums, adjust their investment and risk management strategies including reallocating their assets between geographies and, sectors, and change their involvement in different business lines.⁷⁵

Box 5

Dynamic balance sheet for non-financial sectors

The intensity of transition risks for the financial system depends on the ability and willingness of households, firms and governments to reduce carbon emissions. There are three ways in which these sectors may seek to reduce carbon emissions. The first is increasing energy efficiency by adapting their organisation and technologies. The second is energy transitioning, whereby energy sources with high GHG emissions are replaced by those with lower or no carbon emissions. The third is “carbon removal”, namely technologies that directly remove carbon from the atmosphere.

The private and public sector’s appetite for reducing carbon emissions will depend on the availability of new technologies i.e. technological innovation, and whether these can become economically viable and scaled up across the economy.⁷⁶ Innovation can be either an amplification or a mitigation channel. Technological developments can turn disruptive if they accelerate losses in the competitiveness of industries: for example, fossil fuel providers may decline in importance. However, innovations can mitigate transition risks when they help to reduce carbon emissions (including, but not limited to, solar, wind, biofuels and hydrogen). They may also open up new opportunities (new expertise, jobs, and firms) and enable the shift from a carbon-intensive to a low emission economy.

Innovation may act as a risk mitigant for physical risks by ultimately reducing potential losses arising from adverse extreme weather events. Innovations can also help to moderate potential damage or address the consequence of extreme weather events. For example, they may establish secure water resources and design new infrastructures to reduce vulnerability to climate events (e.g., coastal defences or flood control structures).

One critical element in the adjustments of non-financial sectors to physical risks is the availability and affordability of insurance against extreme weather events. The vulnerability of the financial system will depend on the existing insurance gap (Baudino et al., 2020; BCBS, 2021; FSB, 2020).

⁷⁴ A bottom-up exercise based on three NGFS scenarios that focus on transition risk and chronic physical risks for banks and insurance. This study applies both orderly and disorderly transition scenarios, driven by productivity shocks and sudden increase in carbon prices. The baseline scenario follows the NGFS narrative of an orderly transition. In addition, two disorderly scenarios display a potential delayed transition: the first relates to the sudden disruptive implementation of climate policies starting from 2030; the second depicts a sudden transition starting from 2025 with lower technological innovations and decreasing productivity. The scenarios tend to minimise or ignore acute physical risks.

⁷⁵ EIOPA (2022a) discusses the possibility of a similar twofold exercise based on a constant and constrained dynamic balance sheet (with selected management actions) stress test to assess insurers’ individual vulnerabilities to climate risks.

⁷⁶ An illustrative example of the importance of the propagations of technological innovation versus breakthroughs having potentially different effects on climate-related risks and their overall impact on firms’ balance sheets can be found in Gans, 2012.



Better information on risk may reduce the insurance gap by enabling better quantification of the risk under consideration (i.e. allowing for risk-sensitive and counterparty-specific pricing).⁷⁷ However, risk repricing might also lead to reductions in insurance coverage, especially in vulnerable geographical areas.⁷⁸

Finally, the ability of firms' balance sheets to adapt to any climate risks will also depend on regulatory developments and the availability of funds. In this respect, the formal adoption of the EU green taxonomy for sustainable activities by market participants (Regulation (EU) 2019/2088⁷⁹) is intended to help reduce uncertainty surrounding the classification of green/non-green carbon intensive activities by providing a single common standard across the European Union. It allows comparable and consistent climate-related risk assessments. However, ongoing challenges related to the implementation of the taxonomy, existing data gaps, greenwashing problems and the overall ability of institutions to assess climate-related risks may limit their ability to adjust balance sheets.

Any adjustments are likely to be costly. Their implementation will depend on many factors, including the relevant prices, which are a key driver of economic decisions, competition, consumer preferences and public opinion (demand for goods but also the social sustainability of certain transition measures, which may hit certain categories of customers disproportionately), climate and industrial policies (possibly including bans but also financial incentives such as subsidies or tax breaks and disincentives such as specific taxes), land availability and technological developments.

3.5.1 The scope of dynamic balance sheets of financial institutions

The type and, most importantly, the timing of actions to manage climate-related exposures will differ between banks, insurers and investment funds.

The overview of potential management actions by financial sector segment shows that most management actions by investment funds can be taken in a relatively short time, with insurers being the slowest to adapt due to the long-term nature of their business model, and banks in the middle of the spectrum. The gains from forward-looking management policies are largest for the insurance sector followed by the banking sector. The overview also shows that banks and insurers in particular have many potential ways of adapting and mitigating climate risks.

3.5.1.1 Banks

Banks are most likely to prefer to adjust their balance sheets gradually over a period of several years (Table 9). They can adjust their marketable assets and other securities portfolios.

⁷⁷ The lack of insurance could be due to the lack of risk data and the frequency and severity of the events that make insurance non-viable and reduce the affordability of insurance contracts.

⁷⁸ Affordable insurance for housing due to flood risks is already limited in several districts/areas, including Sydney, Shanghai, Miami, and some areas of New York.

⁷⁹ Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector (OJ L 317, 9.12.2019, p. 1).



However, these represent a relatively small share of total assets.⁸⁰ Any revisions of credit policies that increase the loan's interest rate to reflect heightened risk, reduce the loan's tenor to shorten the period in which the bank will be exposed, requiring protection and risk mitigation for part of the exposure (e.g. guarantees or collateral, but also loan syndications) or contractually requiring the counterparties to comply with certain conditions through loan covenants⁸¹, will first affect new loan origination and new counterparties or projects.

Changes in lending conditions for existing loans take place at regular intervals, typically during a periodic (usually annual) credit review and/or when loans are up for renewal.

Existing loans represent the largest share of loan portfolios. Moreover, bank lending is based on medium or long-term business relationships, and banks have a strong incentive to maintain these. Rather than disinvesting from certain counterparties, banks may choose to support their customers in their efforts to decarbonise and differentiate the terms and conditions of their lending to reflect climate-related risks.⁸²

Banks may attempt to increase their resilience by modifying their funding structure, restoring their profitability and reinforcing their capital positions. For the former, they may reduce their reliance on short-term wholesale market-based funding from corporate customers, other banks or financial institutions, and reduce the risk of massive withdrawal or non-renewal during periods of market turmoil. The realisation or anticipation of losses could induce banks to curtail their discretionary distributions to shareholders or lead them to recapitalise.

While banks have incentives to adapt only gradually, in certain cases, the decisions made can result in significant changes in strategies and business models. For large international banks, these may include sales of subsidiaries located in fossil-fuel-producing jurisdictions and specialised in funding such activities, they may also include the curtailing of certain types of lending.⁸³

⁸⁰ As a result of the revisions in international regulatory standards since 2009, banks have reduced the size of their securities portfolios held for market-making or trading purposes, and increased reserves of liquid assets in order to better withstand market shocks. They can therefore, banks can be expected to become more resilient to bank runs.

⁸¹ These are clauses included in a loan contract that require the borrower to fulfil certain conditions. Failure on the part of the borrower to meet these conditions after the loan is granted may result in action being taken against the borrower, including penalties, or even the declaration of a default by the lender. One example where a bank may support its customers in their efforts to transition to lower emissions are loans that can be extended (or renewed) to corporate customer on condition that it meets certain predetermined targets (for instance a reduction in CO₂ emissions) by a certain date as part of its transition plan.

⁸² Developments since 2015 regarding the financing of large international projects, especially those involving fossil fuel exploration and production, are a case in point. While the financing of existing oil and gas production has not been curtailed and existing fields may continue to be developed, both energy firms and the large international banks that partner with them have become more reluctant and more selective when engaging in oil and gas exploration. However, the persisting imbalance between global energy supply and demand, reinforced by geopolitical tensions, may put a stop to this growing trend at least temporarily.

⁸³ Since 2015 in particular, a number of projects around the world, particularly those involving oil and/or gas exploration, have been delayed or even cancelled, partly because international banks have become more reluctant to fund increases in fossil fuel capacity and partly because energy producers themselves have curtailed such investments and focused on developing existing fields or mines.



Table 9

Balance sheet adaptations by banks

	Short-term	Long term (1 to 5 years)
Assets	<ul style="list-style-type: none"> Reducing reserves (sale) of liquid assets Curtailing market-related activities Adjusting holdings (sale) of non-liquid/high risk tradable assets Cancellation of uncommitted credit lines to other institutions Non-renewal of short-term interbank lending and/or reduction of lending maturities Non-renewal of loans coming due Renewal of non-bank loans coming due with changed (higher) rates, loan tenor (shorter), etc. 	<ul style="list-style-type: none"> Moving out of "higher-risk" business lines Limiting bond and equity syndications/originations Stopping involvement in high yield bonds and/or structured finance and/or proprietary trading Limiting market making activities on secondary markets through widening of bid-offer spreads Curtailing loan origination (especially for large cross-border projects) Curtailing commercial real estate lending Tightening underwriting practices in retail and/or corporate lending, higher rates and/or switching from fixed to floating rates for mortgage loans, requiring higher down payments and enforcing more strictly lending limits
Liabilities	<ul style="list-style-type: none"> Use of high yield assets in asset swaps against liquid securities with institutional non-bank investors Draw down available credit lines (committed and uncommitted) Use of high-quality assets (liquid assets) to source secured lending Accelerate cash inflows, delay cash outflows 	<ul style="list-style-type: none"> Centralized and group-wide liquidity risk management and allocations Lengthening average maturity of funding Constitution of reserves of liquid assets/eligible collateral and pre-positioning of collateral according to potential needs during a liquidity run Finalizing in advance documentation for borrowing programs so that they can be executed as soon as markets show signs of strain
Capital (and profitability)	<ul style="list-style-type: none"> Suspension of discretionary distributions to shareholders (dividends and share-buy-backs) and to staff (bonuses) Raising equity 	<ul style="list-style-type: none"> Cost reduction Imposing group-wide minimum risk-adjusted returns on equity targets for each business line Closure of business lines and/or sales of insufficiently profitable subsidiaries (in risk-adjusted terms) Centralized and risk adjusted allocations on economic (and regulatory) capital Limiting/curtailing all discretionary cash distributions, payment of discretionary distributions to staff and executives in shares or in ad hoc deeply subordinated instruments, payment of dividends in common shares

Notes: The adjustment mechanisms are tentatively sorted from quickest, coming first in each category, to slowest, coming last in each category.

3.5.1.2 Insurers

Insurers' investment strategies are designed to match their liability structure, i.e. commitments towards policyholders. Liabilities, especially in the life business, generally have long durations and their conditions are defined at contract inception. Many actions taken by



insurers in response to climate-related shocks are only visible in the long term. Moreover, these actions should be interpreted in the light of the Solvency II regime which requires a full market valuation of assets and liabilities and a value at risk-based approach to capital requirements. The implementation of a dynamic balance sheet in a stress test has been explored in the EIOPA 2021 Insurance stress test. Reactive management actions mainly include capital increases (e.g. through equity issuance or asset sales), changes in the investment portfolio (e.g. through divestments), repricing, reductions in expenses (e.g. staff layoffs), hedging of exposures and/or dividend and profit-sharing decisions (Table 10).⁸⁴

Table 10
Balance sheet adaptations by insurers

	Short-term	Other (short or long-term)
Assets	De-risking of the asset portfolio by changing portfolio composition, e.g. between equity and debt assets, moving towards higher-rated assets Applying hedging strategies	Change in the strategic asset allocation, e.g. reassessing the geographic location of investments in real estate assets Divestment of certain types of assets
Liabilities	Adjustments to underwriting strategies for non-life products by pricing adjustments and contractual features such as coverage limits or exclusions Strategic underwriting decisions for non-life products, such as stopping underwriting coverage of specific risks (e.g. cyber, natcat, health)	Adjustments to the underwriting strategy for life products, e.g. a shift towards unit-linked and index-linked business ⁸⁵ Reducing exposure to insurance liability ⁸⁶ Adjustments to product offerings
Capital (and profitability)	Retention of profits e.g. earnings to shareholders Reduction of discretionary benefits embedded in specific life product portfolios Issuance of subordinated debt according to the capital management policy of the insurer	Recapitalisation Cost reduction
Solvency	Adjustment of risk-transfer strategies, i.e. reinsurance agreements	Own Risk Solvency Assessment

Note: The adjustment mechanisms are tentatively listed in order of the quickest (first in each category), to the slowest (coming last in each category).

The application of reactive management actions in a potential climate stress test is quite complex. From a technical perspective, prescribing specific going-concern assumptions, such as defining specific limits on asset allocations, requires specific adjustments to the stochastic valuation and risk models of insurers even if these are not necessarily designed for such applications.

⁸⁴ Most of the reactive management actions by participants related to solvency position and had no impact on the balance sheet position. Notably: 11 participants decided not to distribute dividends, while eight participants applied a de-risking strategy on the asset side of the balance sheet. In addition, six participants increased their capital through recapitalisation or by issuing subordinate debt. Other actions included the reduction of costs, a de-risking strategy on the liabilities side of the balance sheet involving the reduction of the discretionary benefits, and the use of a pre-approved VA or a change of reinsurance strategy/coverages.

⁸⁵ In this type of business, insurance companies use a portion of premiums to buy units in investment funds and to provide coverage while the policyholder bears all the investment risk.

⁸⁶ This kind of insurance contract pays third parties and not policyholders for several types of damage.



3.5.1.3 Investment funds

Investment funds operate as an interface between investors and issuers. The balance sheets of investment funds are simpler than those of banks or insurance companies. A fund manager establishes an investment strategy, and the money invested in an investment fund is directly reflected in the value of its shares and new assets.⁸⁷ However, funds are exposed to the short-term risks of fast-moving redemptions (reflecting competitive pressure in the investment fund sector) and have to continuously adapt to an evolving supply of different investable securities (i.e. the assets in which funds invest).

For investment funds, their dynamic balance sheet perspective boils down to their strategies for dealing with outflows (redemptions) or inflows from investors (Table 11).

Redemptions may appear when climate risk shock affects investment fund assets or as a reflection of evolving investors preferences, for example, investors may become increasingly concerned about climate-related factors and include them more systematically and consistently in their investment decisions. In the very short term, outflows can be mitigated somewhat using liquidity-management tools (although this also has a reputational cost). More often, investment funds either rebalance their portfolios to return to their long term target allocation or adjust their target allocation and implement this adjusted target.

Table 11
Balance sheet adaptations by funds

	Short-term	Other (short or long-term)
Assets	<ul style="list-style-type: none"> Rebalancing of asset portfolio to return to the previous target allocation 	<ul style="list-style-type: none"> Divesting of specific assets and investing in completely new assets Choosing to hold cash Adjusting target allocation and implementing this adjusted target Emergence or closure of investment funds
Liabilities	<ul style="list-style-type: none"> Redemptions or inflows to an existing investment fund Liquidity-management tools 	

Notes: The adjustment mechanisms are tentatively listed in order of the quickest (first in each category) to the slowest (last in each category)

Some of the challenges involved in dynamic balance sheet modelling are particularly salient to the investment fund sector. On the assets side, these involve describing the rules of investment fund asset rebalancing decisions, which could take the form of certain "rules" or "ladders" for discriminating against/preferring specific assets and elaborating on how easily and how quickly investment policies can be modified. The dynamic balance sheet can also involve liquidity consideration. On the liabilities side, the implementation of a dynamic balance sheet

⁸⁷ In the most straightforward case of an open-end fund, each time money is invested, new shares or units are created to match the prevailing share price; each time shares are redeemed, the assets sold match the prevailing share price.



perspective requires the estimation of both short-term (i.e. intra-month) and long term elasticities of inflows and outflows following fund performance.⁸⁸

3.6 Amplification and sectoral interactions for climate risks

Climate risk may be amplified by rigidities in the real economy. On the demand side, real frictions such as stickiness in consumption may amplify transition shocks, representing a failure on the part of consumers to incorporate sustainability considerations into their behaviour in a timely manner. On the supply side, the presence of technological constraints and adjustment costs for the roll-out of green investments may exacerbate transition risks, making firms' response to climate policy sluggish. The presence of rigidities in the labour market, such a limited sectorial labour mobility, is also a source of amplification, as it prevents an efficient employment reallocation that is consistent with the transition to a carbon-neutral economy.

Potential disruptions to supply chains could become another real economy amplifier. These may emerge due to shortages of raw materials and exacerbate costs for energy derived from fossil fuels. While higher fossil energy costs could act as a deterrent for the adoption of carbon-intensive production inputs thereby accelerating the transition, they need to be matched by the availability of alternative cleaner energy options to ensure a smooth transition (Box 6).

Box 6 Supply chain networks

This box looks into vulnerabilities in the supply chain networks to transition and two different physical risks: floods and wildfires.⁸⁹ The analysis relies on a representation of almost 200,000 individual trade links between over 50,000 EU firms⁹⁰, one third of which are in manufacturing. The firms have a substantial number of outgoing (incoming) links: 20% of them have more than seven connections and 1% have more than 75 connections.

Although most of the firms have a low to medium exposure to climate risks, there is a small, but not negligible, number of firms with a high exposure to transition or physical risk.⁹¹ For each firm, its

⁸⁸ Some instrument types and asset classes are also challenging to model, e.g. futures/forwards, structured finance and options, due to lack of data,; complicated valuation techniques are used, for example, for options or short positions.

⁸⁹ The analysis is described in detail in Ojea-Ferreiro et al. (2022).

⁹⁰ The supply chain network data is sourced from FactSet.

⁹¹ To check how resilient the economy is to climate risk accounting for value chains, firms are removed iteratively from the network following a certain criterion in the removal process, e.g. from the most to the less pollutant, from the most exposed to floods to the less exposed, After each iteration, the length of the longest value chain is computed, the more important is the sorting criterion for the interconnectedness of the network, the higher is the decrease in the longest length of the value chain. Overall, the physical and transition risks criteria impact much less in the supply chain than statistical-based criteria, i.e. removing firms from the highest degree to the lowest degree.



transition risk exposure is proxied by its carbon emissions exposure score⁹² and the physical risk exposure by risk scores for floods and wildfires as anticipated in 2050.^{93 94}

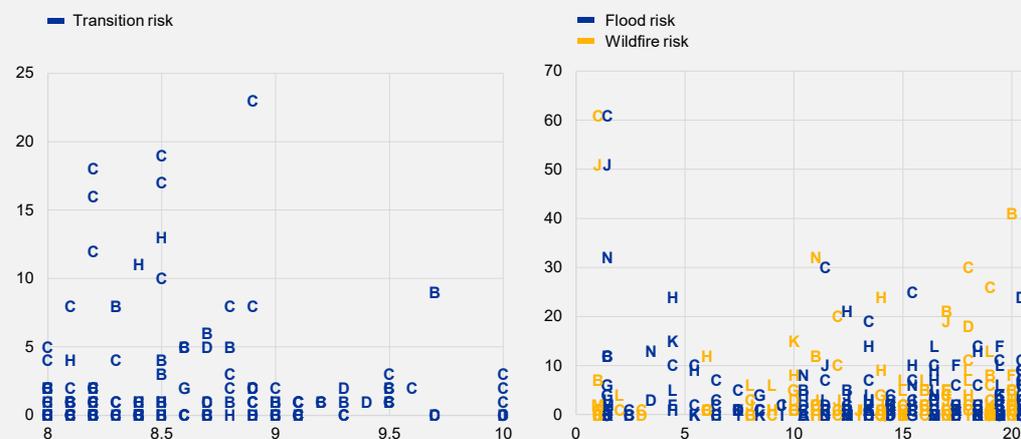
Several of the highly connected firms are subject to high transition risks. These highly exposed firms (3% of the sample) could affect more than 10% of the firms, taking all trading partners into account. Thus, a severe and abrupt shock that affects them first could propagate through the supply chain and affect a far larger number of firms in terms of reduced profits and product shortages, among other things. The sector with the highest climate transition risk exposure and the highest connectivity is manufacturing (C), followed by transportation and storage (H), with firms in these sectors having more than ten customers on average according to the left-hand panel of Chart A.

Firms highly exposed to flood and wildfire risk are strongly connected in the network. Although these firms make up about 1.5% of the sample, they supply their products or services to, or purchase goods and services from, between 5% to 7% of the firms. As shown in the right-hand panel in Chart 1, the dominant sectors in terms of high risk and high connectedness are manufacturing (C), followed by transportation (H) and information and communication (J).

Chart A

Sectoral distribution of firms with high climate transition (left-hand panel) and physical risk (right-hand panel; flood in blue, wildfire in red) scores and large number of customers.

(y-axis (lhs): number of customers, x-axis (lhs): carbon emissions exposure score, y-axis (rhs): number of customers, x-axis (rhs): physical risk score)



Note: The letters refer to the NACE Rev.2 Sections. A: Agriculture, B: Mining, C: Manufacturing, D: Electricity, E: Water, F: Construction, G: Retail, H: Transport, I: Accommodation, J: Info.Communic, K: Finance/Insur, L: Real.Estate, M: Prof.Scient.Tech, N: Admin, O: Public Admin.Defen, P: Education, Q: Health, R: Arts.Entert, S: OtherService, T: Household, U: ExtraterrOrg. The higher the firm, the more customers it has, and the further it is to the right, the greater its vulnerability to the respective climate risk. The size of the climate risk is proportional to the number of customer links of each firm.

⁹² The higher the score, the higher the risk, MSCI (2021).

⁹³ The lower the score, the higher the risk, ISS (2021).

⁹⁴ Coupling the network with transition and physical risk indicators reduces the sample by a factor of 10 for transition risks (i.e. to around 5 thousand enterprises) and about 4 times for physical risks (i.e. to around 12 thousand enterprises). This results into a different percentage of highly exposed firms depending on the climate risk type.



The analysis of the supply links from non-financial corporations (NFCs) to financial institutions (FIs) shows that most suppliers to financial firms have a medium-to-low exposure to climate change risk. Only a few firms, mostly in the manufacturing sector, have a medium-to-high carbon risk exposure and few supply links to the financial sector. Similarly, most financial sector suppliers have medium-to-low physical risk exposures. Those NFCs with high physical risk also have a low number of customer links, indicating that, if flood or wildfire risks materialize, the shocks will not propagate easily. Overall, operational climate-related risks to the financial sector seem to be contained.

In the financial sector, amplification may arise because of market participant behaviours. For instance, divestment by investment funds will affect asset prices, given the large size of the investment fund sector (Box 7). Certain sectors and geographies will experience severe capital outflows (and others capital inflows), leading to the revaluation of certain industries, as well as economies. The adjusted asset prices in turn further affect fund asset performance, resulting in further redemptions, rebalancing, asset price impacts, etc. Additionally, issuers of securities may be increasingly likely to mitigate risks related to their climate-related exposures (e.g. reduce carbon emissions or avoid areas that are prone to certain climate-related physical disruptions, such as floodable areas).⁹⁵

Market structure and interconnectedness represent a major vulnerability, as they can generate spillovers involving other areas of the financial system. A market structure characterised by a highly interconnected financial sector is more sensitive to the propagation of transition risk shocks. For instance, banks may be exposed to significant – but indirect and “hidden”- risk concentrations, including climate-related ones, through their financing of non-banking financial institutions.⁹⁶ This may be the case, in particular, in their prime brokerage activities for hedge funds, family offices, private equity, and unregulated investment funds more generally. On the liabilities side, banks can ensure enough diversification by counterpart of their short-term wholesale funding provided by investment funds. However, they are less aware of the investments made by these funds and to what extent these funds may be exposed to similar investments, including in carbon-intensive sectors.

Box 7 Dual risk in investment fund climate stress testing

This box develops a framework for the climate risk stress testing of investment funds with two layers of contagion.⁹⁷ The first contagion layer relates to crossholdings of investment funds, and changes in the value of shares issued by open-end funds that are held by other funds. The second layer is the overlapping exposures on the secondary market for securities, whereby investment funds may be exposed to common shocks, but may also affect one another by influencing market prices through sales and purchases. The model is tailored to short-term scenarios, plausibly

⁹⁵ This could generate a feedback loop. Should all banks and insurers enter into risk avoidance strategies and start refusing to lend/insure against housing located on floodable coast/rivers, the consequences in terms of the value of the related properties and in terms of financial inclusion may be significant, including in Europe, and may even lead to the extension of government-sponsored schemes as is already the case in some areas (with regards to natural disasters affecting crops in particular).

⁹⁶ A recent illustration of such concentration is the case of Archegos, a family office run by an ex-hedge fund manager, which accumulated large, concentrated equity positions in a small number of high-tech, not fully liquid and volatile, shares.

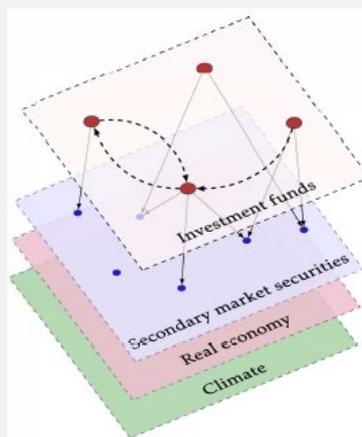
⁹⁷ The analysis is described in detail in Gourdel and Sydow (2022).



unfolding over a few weeks, and allows for market shocks, i.e. changes in the values of traded securities, as well as liquidity shocks arising due to redemptions by investors. The analysis leverages several proprietary data sets covering climate-related variables for the real economy and investment funds balance sheets and provides a dual view of transition and physical climate risk exposures at the fund level.

Figure A

Stylised representation of the network agents and key links transmitting economic shocks.



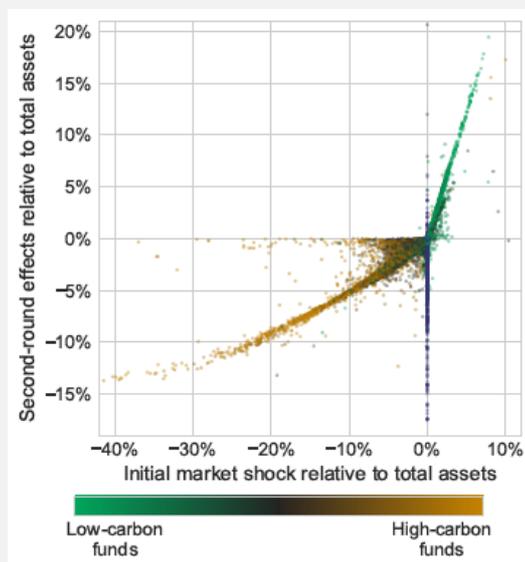
Note: The dashed arrows indicate crossholdings between funds, while the solid lines indicate that a security is present in the portfolio of a fund.

A stress test based on short-term transition shocks suggests that the integration of sustainability information by funds has made network amplification less likely. The first-round effect of a market shock driven by transition risk for individual funds is represented in Chart A. By design, the shock penalises securities of high-carbon issuers, and benefits low-carbon issuers, where the shock calibration takes into account the history of observed returns at the security level. Overall, “greener” funds display better results, while non-green funds may suffer consequent stress. Some of the funds (in dark blue on the map) are not affected directly by the shock because few of their assets have associated carbon emission data. However, as can be read from the y-axis, some of the funds may still be significantly exposed to second-round effects. These second-round effects stem from both contagion channels, although few high-risk profile funds are exposed to both contagion channels at the same time.



Chart A

Scatter plot of results by investment funds for a transition risk market shock.



Notes: The x-axis represents the initial shock incurred by investment funds, i.e. the losses generated by price changes on the secondary market. The y-axis represents the sum of the following second-round effects, due to the revaluation of inter-fund holdings, flows from investors, and the consequences of fire sales triggered by liquidity stress. On both axes, the values used for each fund are normalised by the fund's initial equity. For each fund, the weighted average of its portfolio carbon emissions determines the colour of the corresponding dot, with low-carbon funds being greener and high-carbon funds more non-green. A threshold is applied such that funds whose portfolios have too much missing carbon emission data are given a dark blue colour. Several outliers are not represented in the chart.

Investors in “green” funds react less to losses but reward funds with more positive flows when they exhibit positive returns. This feature, which distinguishes funds with an environmental profile from others, explains the fact that the slope in the top-right section of the chart, where many low-carbon funds are concentrated, is steeper than that of the high-carbon funds in the bottom left section of the chart. This flow-performance reaction appears to be a key determinant of the ratio of the total second-round to first-round effects. Market shocks could have important consequences in terms of flows reallocated from high-carbon to low-carbon investment funds, although their timing is more likely to increase financial instability than facilitate useful investment in low-carbon sectors.

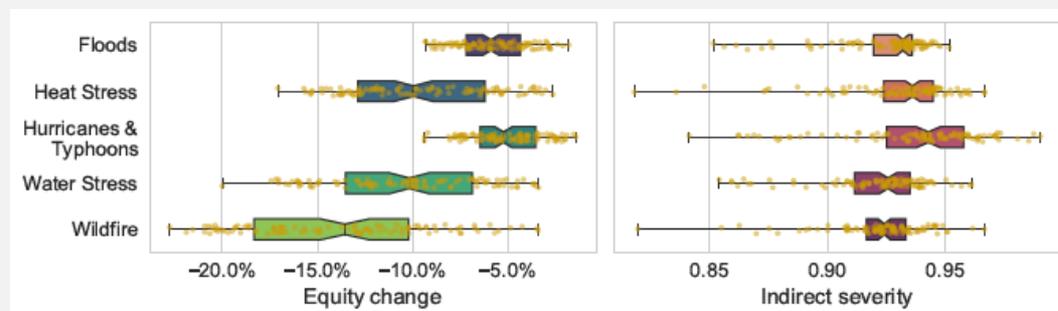
Investment funds absorb physical risk less efficiently than transition shocks, demonstrating that there is room for better fund management and regulation. Market shocks driven by physical risk information and by the materialisation of extreme weather events are presented in Chart B.⁹⁸ Because funds exhibit a lack of differentiation relative to physical risk, the impact appears significantly more uniform than for transition risk. However, wildfire, water stress and heat stress are tail events that damage investment funds the most. Improving transparency and setting relevant industry standards in this context would help mitigate short-term financial stability risks.

⁹⁸ In this scenario, the shock materialises in two steps. First, a connected series of extreme weather events occurs. This causes a loss of profitability or complete default for firms as they lose part of their physical assets or are impaired in their operations, because their immediate environment or segments of their supply chain are affected. Second, the price of the assets declines on the basis of this event.



Chart B

Results for a range of physical risk shocks based on firms' exposures



Notes: The box plots and scatter plots correspond for each shock category to a total of 100 Monte Carlo simulations, produced from shocks generated based on exposures to physical risks. Notches on the boxplots represent the confidence interval around the median. Left-hand panel: total equity change of the sector, i.e. after summing over all funds, in the course of the simulation. Right-hand panel: indirect severity of the simulations, i.e. the level of indirect damage against that of a similar uniform shock.

3.6.1 Interconnectedness and amplification effects following a severe climate risk shock scenario through a system-wide perspective

The long-term scenarios feed into an interconnected financial system of banks, investment funds and insurance companies in the ECB system-wide stress test (SWST) framework. The SWST has been developed together with national central banks and is tailored to analyse interconnectedness and amplification effects within the euro area financial system.^{99,100}

The model uses the network configuration, depicted in Chart 36 using granular data, to replicate bank-to-bank and bank to other financial and real economy sector exposures.¹⁰¹

Zooming in, the banking sector is comprised of 166 consolidated banking groups. The insurance sector includes 18 country-level euro area company aggregates, which are connected to the other two sectors - banks and funds - via the securities they hold.¹⁰² The investment fund sector includes

⁹⁹ See Sydow et al. (2021) for methodological details.

¹⁰⁰ Earlier works that jointly model multiple financial sectors using real-world, institution-level data, in the context of climate change scenarios include Roncoroni et al. (2021a), who study banks and investment fund interactions as well as the implications of asset contagion and endogenous recovery rates. Gourdel and Sydow (2022) study systemic failures driven by network externalities and develop a short-term climate stress-test model, built on transition and physical risk exposures between funds and firms (see also Box 7 in this report). To estimate a permanent market shift following climate events, a longer-term horizon is introduced by Battiston et al. (2017) and Roncoroni et al. (2021b).

¹⁰¹ The banking dataset includes granular data from COREP (Common Reporting) data at the counterparty-level in combination with FINREP (Financial Reporting) data at the country-sector level and SHS-G (Securities Holdings Statistics by banking group) data at the ISIN-level.

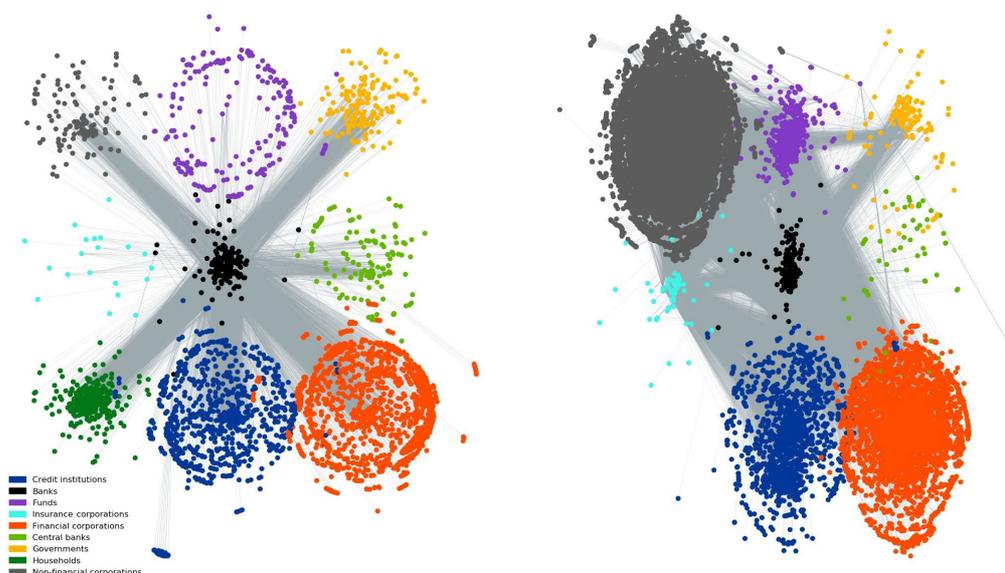
¹⁰² The insurers' dataset includes granular data from SHS-S (Securities Holdings Statistics by institutional sector) data at the ISIN-level, in combination with country-level Solvency II data. LEI (Legal Entity Identifier), RIAD (Register of Institutions and Affiliates Data) and ISIN codes are extrapolated from the Moody's, GLEIF (Global Legal Entity Identifier Foundation), RIAD and CSDB (Centralised Securities Database) databases to uniquely identify the securities issues and the corresponding issuers. Following a data matching procedure, all the entities in our sample are included under the nodes, to which they are related.



10,555 open-ended funds, which hold marketable securities and are interconnected and connected - via granular intra- and intersectoral exposures - to banks, insurers and financial corporations.¹⁰³

Chart 35

Loans (left-hand side) and security holdings (right-hand side) exposure networks



Source: Authors' calculations.

Notes: On the left, an edge represents a loan from a bank to another entity in each sector, while on the right an edge shows that a bank/fund/insurer holds assets issued by another entity in a given sector. Credit institutions exclude consolidated banking groups. Financial corporations cover all financial entities, such as credit institutions and insurers, but exclude banking groups and insurance aggregates.

Interconnections between sectors give rise to several contagion channels within the system.

Funds and insurers deposit their cash at banks, which in turn provide them with loans; moreover, all three sectoral agents hold each other's securities. The initial credit risk shock triggers defaults by firms and causes markets to re-price the tradable assets issued by these firms. This causes revaluations of all the securities' holdings of banks, insurers and investment funds. This means that funds' net asset values are also affected, prompting investors, including financial institutions in the system, to start redeeming their fund shares (assuming no gating of redemptions). Funds hold at the limited amount of cash and when they need liquidity, they can sell portions of their securities and possibly trigger fire sales. Insurers sell their securities instantaneously when

¹⁰³ The funds dataset covering bond, equity and mixed funds includes granular data coming from Lipper IM by Refinitiv, in combination with QSA (Quarterly Sector Accounts) and IVF (Investment Funds Balance Sheet Statistics) data at the aggregate fund sector-level, compiled by the ECB.

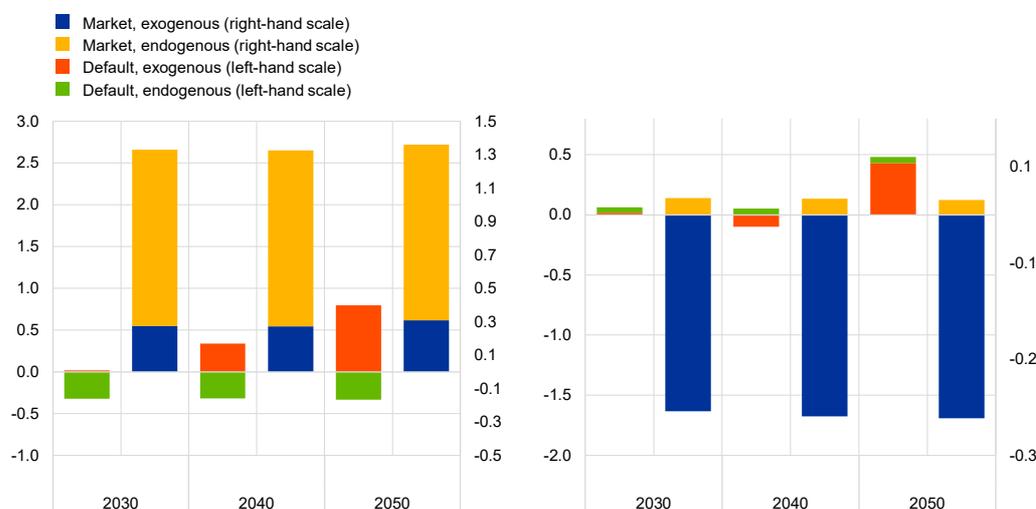


breaching their capital requirement.¹⁰⁴ Banks, when faced with liquidity shortfalls, will sell their non-eligible assets (they will not sell high-quality liquid assets as these are used to access funding from the central bank) including at discounted prices. The model recalculates the impact of these endogenous reactions on the liquidity status of all agents in the system until convergence.

In a first round, the financial system is affected by the NGFS macro-financial scenarios via an increase in credit risk on banks' corporate loan portfolios and asset revaluations of tradable securities held by insurers and investment funds. Chart 36 shows the system-level losses under the net zero and delayed transition scenarios relative to the current policies scenario. The first-round impact on credit (PD and LGD) and market risk (asset valuations) is matched with the estimates in Section 3. The timely phase-in of transition policies in the net zero 2050 scenario brings about direct reduction in revaluation losses compared with the current policies scenario, amounting to around 0.2% of system assets as soon as 2030, and prevents an increase in corporate defaults, although the latter impact is less material. The delayed phase-in of transition policies in the delayed transition scenario results in revaluation losses of around 0.4% and limited decrease in credit risk losses.

Chart 36
System-specific losses in the net zero (left-hand side) and delayed transition (right-hand side) scenario relative to the current policies scenario.

X-axis: years; Y-axis: losses expressed in terms of total assets in the system, per cent mille (left-hand scale), percentage (right-hand scale)



Sources: Authors' calculations.

Notes: "Default, first-round" refers to NFC defaults. "Market, first-round" refers to exogenous market losses both due to the

¹⁰⁴ This is a strong and conservative assumption provided that Solvency II encompasses macroprudential tools such as the long-term guarantees package which aim to absorb volatility in the financial markets and avoid fire sales of assets. The framework also allows a six-month period to re-establish the level of eligible own funds to cover the solvency capital requirement, or to reduce the risk profile of the undertaking to ensure compliance. Accordingly, the fire sale of assets is not the first option indicated by insurers as an adjustment to stress in the 2021 EU-wide Insurance stress test exercise. It is also worth noting that the model does not account for changes in the values of the liabilities triggered by long-term guarantees and discretionary benefits and ignores the effect of the loss absorbing capacity of technical provisions and deferred taxes.



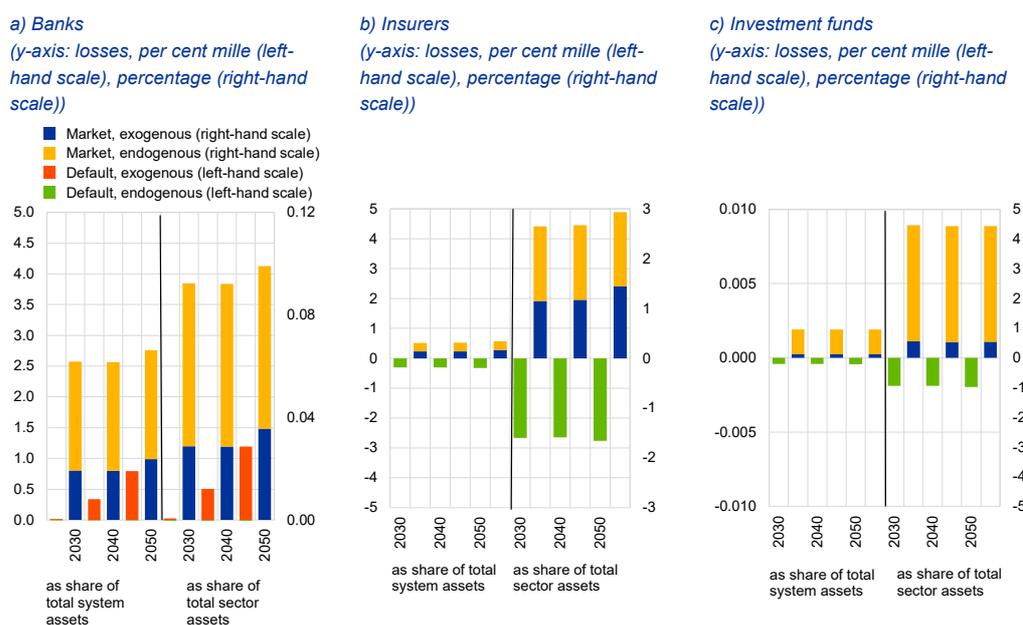
market scenario and due to the price drop of exogenously defaulting NFCs issuing securities. “Second-round” losses are model-driven. The left-hand axes are expressed in pcm (per cent mille) and the right-hand axes in %.

System-wide amplification of initial market risk shocks increases the reduction in relative revaluation losses under the net zero 2050 compared with the current policies scenario over four times.¹⁰⁵ The reduction in the second-round (endogenous) market losses in the net zero scenario is more than three times larger than those for the first-round (exogenous) market losses (Chart 36, left panel). The second-round corporate defaults are moderately higher than in the current policies scenario, but overall, credit risk decreases over time due to the timely phase-in of transition policies.

Market risk losses in the delayed transition scenario are overall larger than in the current policies scenario. Second-round effects on assets valuation in the delayed transition compared to the current policies scenario have a non-negligible positive impact on the financial system, but are overshadowed by first-round losses that are more than ten times larger (Chart 36, right panel). The amplification of credit risk plays a very modest role in explaining the differences between the delayed transition and current policies scenarios.

Chart 37

Sector-specific losses under the net zero scenario relative to the current policies scenario



Source: Authors' calculations.

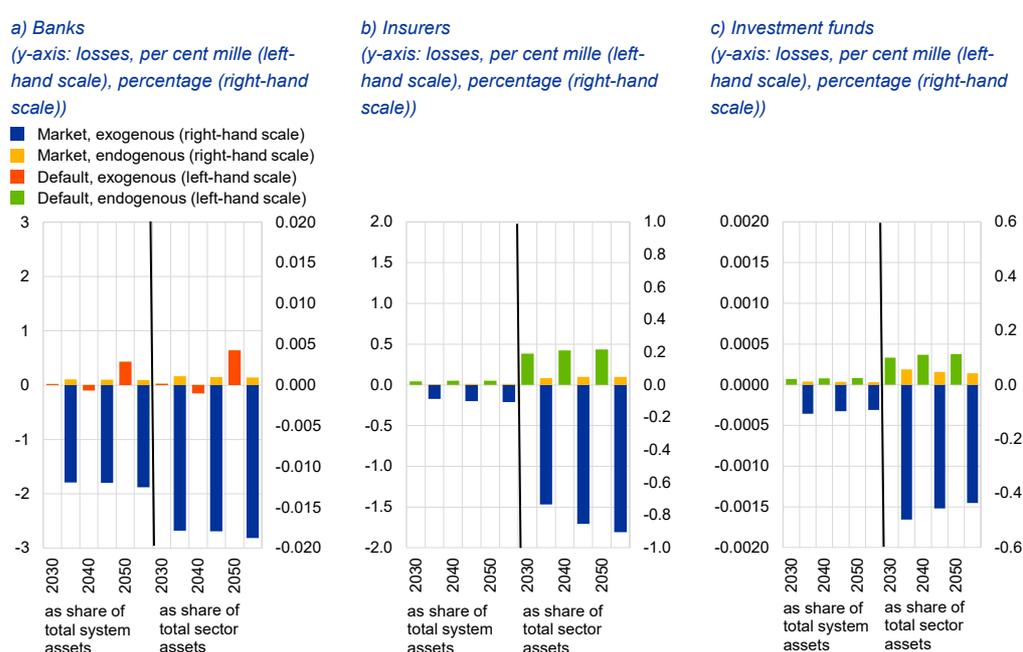
Notes: “Default, first-round” refers to NFC defaults. “Market, first-round” refers to exogenous market losses both due to the market scenario and due to the price drop of exogenously defaulting NFCs issuing securities. “Second-round” losses are model-driven. The left-hand axes are expressed in pcm (per cent mille) and the right-hand axes in %.

¹⁰⁵ Using a median price impact calibration (see Fukker et al., 2022), estimated at the level of individual securities for the net zero scenario, and a price-at-risk calibration for the current policies and delayed transition scenarios.



The net zero 2050 scenario is reflected in revaluation gains for all financial sectors (Chart 37). Default losses hardly play a role for any of the sectors. The positive second-round effects on asset valuation are higher than the first-round gains in banking and investment funds. For insurers the first-round effects play a relatively larger role than the second-round impact, given the lower importance of fire sale mechanisms for insurers. Looking at the magnitudes, the gains from early transition are largest for investment funds amounting to 4% of their total assets, followed by insurers, between 2.5% and 3%, and lowest for banks, at less than 0.1%.

Chart 38
Sector-specific losses in the delayed transition scenario relative to the current policies scenario



Source: Authors' calculations.

Notes: "Default, first-round" refers to NFC defaults. "Market, first-round" refers to exogenous market losses both due to the market scenario and due to the price drop of exogenously defaulting NFCs issuing securities. "Second-round" losses are model-driven. The left-hand axes are expressed in pcm (per cent mille) and the right-hand axes in %.

In the delayed transition scenario, all sectors experience significant revaluation losses relative to current policies (Chart 38). The first-round market losses of investment funds, expressed relative to total sector assets, decrease over time reflecting a gradual deleveraging of non-green carbon intensive assets, while the corresponding losses of insurers gradually increase over time. Accordingly, the market losses of investment funds peak in 2030, at 0.5% of sector assets, and the losses of insurers alone in 2050 make up 0.9% of sector assets (they remain negligible for banks). The first- and second-round default losses in the delayed transition scenario are close in terms of magnitude to losses in the current policies scenario.

A market propagation channel results in substantial amplification effects, producing consistently high second-round reduction of market risk losses, particularly in an early and



orderly transition. Insurers and funds experience far higher overall reduction (under the net zero scenario) or losses (under the delayed transition scenario) due to their exposures to each other and to the banking sector.



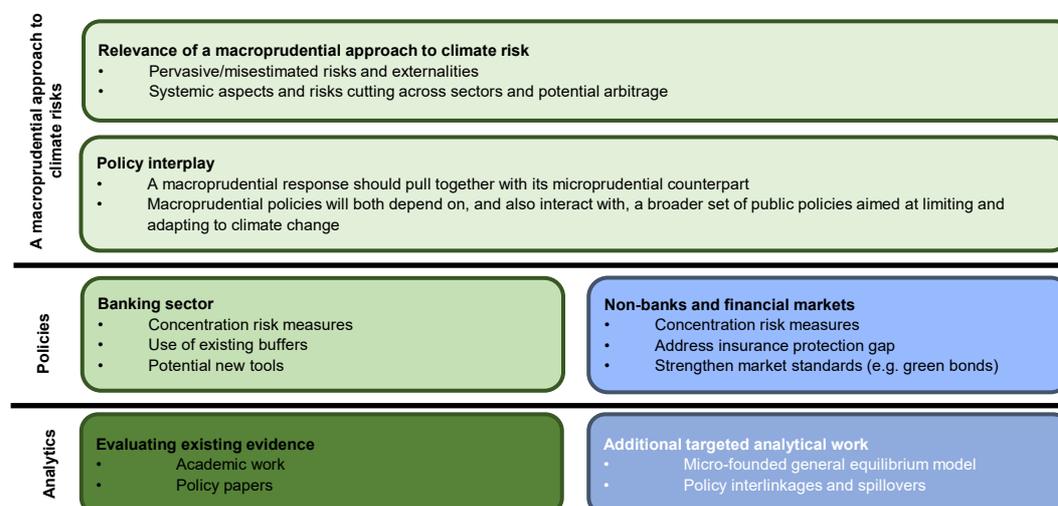
4 Policy considerations

4.1 Introduction and background

Climate change is a major collective challenge that requires strong international cooperation and policy efforts on all fronts. Informational and allocative market failures are inherent to climate change (ECB/ESRB, 2020), and there is a strong risk that climate risks are not fully reflected in asset valuations, highlighting a need for collective leadership and globally coordinated action (NGFS, 2019). Public policies, like carbon pricing, are generally seen as being the first-best policy for combating climate change (Krupnick and Parry, 2012), with the responsibility for enacting such policies lying at the political level (Stern, 2021). However, the unprecedented global nature of climate change calls for a broader policy response, ideally with thorough consideration of the implications of climate change for respective policy frameworks, as well as the interplay between them (Restoy, 2021). Within the narrower realm of financial markets and the real economy, prudential policy will clearly have a specific role to play in this broader policy constellation.

Figure 7

Assessing the need for a macroprudential approach, and policy mapping



In this section, we focus on the specific role of macroprudential policy in addressing systemic aspects of climate-related financial risks. The policy thinking on the consequences of climate change for prudential policy is advancing rapidly. We contribute to this ongoing policy discussion by mapping a growing body of evidence to macroprudential policy, distinguishing between banks, non-banks and markets, and between transition and physical risks. Furthermore, we discuss the interplay of macroprudential policy with microprudential and public policies and



provide conceptual considerations that could help identify policies to manage systemic aspects of climate risks (Figure 7). These considerations build on, and also feed into, European and international initiatives in the sphere of prudential policy (Table 12 as well as Annex 2 on main policy initiatives by institution).

Table 12
Ongoing policy initiatives¹⁰⁶

Policy areas (1)	Financial system	Banks	Insurance	Asset managers
A) Market development and approaches to align investments to sustainability goals	Green Deal, taxonomy (EC); ESG ratings (EC, ESMA); Sustainable finance Roadmap (ESMA, G20); its own investment strategy (e.g. BdF, BoI, Sveriges Riksbank)		ESG factors(EC)	Green bond standards (EC)
B) Information on climate risks, opportunities and impacts	Benchmarks (EC, IOSCO, FSB), Sustainable Finance Disclosures regulation (EC, EBA, EIOPA, ESMA)	Pilot exercise on financial risks linked to climate change (EBA, BdF/ACPR).	Development of a dashboard on insurance protection gap for natural catastrophes (EIOPA)	Disclosures (BCB, MAS, EC, IOSCO)
C) Assessment and management of climate risks		Supervisory expectations (NGFS, ECB/SSM, BoI, DNB, BdF, BoE etc.), integration of ESG risks and factors (EC, EBA), development of a framework for climate risk assessment (ECB/SSM)	Integrate sustainability risks and factors (EC, EIOPA) supervisory expectations (NGFS, BoE), natural catastrophe risk (EIOPA)	Integrate sustainability risks and factors (EC, ESMA); supervisory expectations (NGFS)
Green microprudential regulation		Ongoing discussion on Pillar 1, Pillar 2 and Pillar 3 (EBA, BCBS);	Scenario analysis, solvency capital requirements (EC, EIOPA)	
Green macroprudential regulation		Ongoing discussion (FSB, EBA, ESRB, ECB, EC, BCBS); Capital requirements (United Kingdom, Canada)		
D) Role of IFIs, public finance and incentive	BoJ lending facilities (BoJ), BCB mandatory compliance for accessing credit (BCB),			

Note: BdF: Banque de France, BoI: Banca d'Italia, BoJ: Bank of Japan, MAS: Monetary Authority of Singapore.

¹⁰⁶ The table is based on public available information on the ongoing discussion on policy options at international and European level organized following the structure of the G20 Sustainable Finance Roadmap. For details about the initiatives see Annex 2; the list is not intended to be exhaustive.



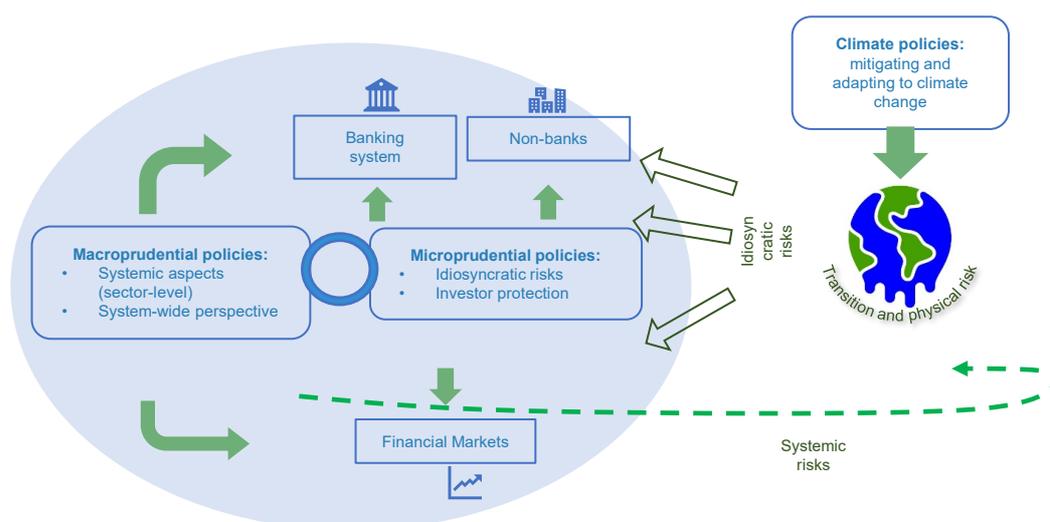
Macroprudential policy targeting systemic aspects of climate risks will help to address both climate-specific and classic externalities.

In general, a prudential approach to financial risk is challenged by the high complexity, long time horizons, tipping points and largely irreversible nature of climate-related risks. High discount rates might accompany such uncertainty, not only in the expectation that such risks may only materialise in the long run, but also given the largely backward-looking nature of existing risk management models, together with data gaps. In such a setting, financial system risk might not be additive, given classic risk externalities caused by interconnectedness, spillovers and second-round effects, amplification due to common asset holdings (see Section 2.3) and the likelihood of transition risks and physical risks increasing in a correlated manner. Other prudential policies also do not address the externality associated with excessive lending to high-carbon projects. While any single loan of this nature does not contribute much to raising risks for the individual institution, it does contribute to a build-up of risks at overall economy and financial system level. All this warrants a macroprudential perspective.

Macroprudential policy can complement a microprudential approach and related supervision targeting idiosyncratic aspects of climate-related risks (Baranović et al., 2021).

In tandem with supervisory efforts and microprudential regulation to address climate-related risks, macroprudential policies and considerations would play an important role in addressing the challenges of climate change for the financial system, focusing on systemic aspects of climate-related risks (Figure 8). By reinforcing each other, the joint and coordinated application would ensure that the financial system is well safeguarded against both transition and physical risks (see Section 4.4 for a detailed discussion on policy interplay and coordination of macroprudential policy). Microprudential and macroprudential policy options can be seen as a continuum, while being mindful of potential trade-offs. In certain cases, amended or new regulatory tools may well be justified both from both a microprudential and a macroprudential perspective.

Figure 8
Putting climate-related macroprudential policy into context



With its system-wide perspective, a macroprudential approach to climate risks, as in the case of other systemic risks, could help to address risks that cut across sectors and limit arbitrage. A consistent macroprudential approach covering all relevant parts of the financial system would help to alleviate possible spillovers between the banking and non-banking sectors, particularly in areas where both bank and non-bank institutions are performing similar activities and have common exposures. Similarly, it would also help to reduce cross-sector arbitrage and limit risk shifting to the less regulated part of the financial system.

4.2 The need for a macroprudential approach to climate risks and its interplay with other policies

Crossholdings and common exposures across the financial system will likely amplify the materialisation of climate risks, warranting the inclusion of a system-wide perspective for the policy response. Section 2.3 highlighted that transition risk as a common risk factor may alter the correlation structure of credit risk and reduce the mitigation possibilities of diversification. Moreover, economic interdependencies and financial networks are needed to account for direct and indirect impacts with risks of contagion and require a systemic approach to policy. Such systemic dimensions of climate risks, which go beyond the idiosyncratic risks of individual institutions and investors, are typically neither covered by microprudential regulation nor internalised by individual entities. The pre-emptive nature of macroprudential policies can ensure adequate resilience in the financial system to cope with any shocks in the longer term. This is highly relevant given the uncertainties surrounding climate risks.

Compared with other policies, a macroprudential approach to climate risks is likely best placed to address the externality associated with excessive lending to high carbon projects. While not contributing much to increasing the individual risk of institutions, such aggregate lending does contribute to a build-up of risks at the economy and financial system level. Macroprudential policy, with its system-wide perspective, is there to address the build-up of risks arising from collective lending decisions by financial institutions and can help to strengthen the resilience of the financial system when losses stemming from such lending materialise.

Banking sector

Both climate change and climate change mitigation will expose the banking sector to new kinds of risks with potential systemic implications that are not fully captured within its current regulatory framework. Work by the Basel Committee on Banking Supervision (BCBS) and the European Banking Authority (EBA) to date indicates that almost all drivers of climate risk, including physical and transition risks, can be captured in traditional financial risk categories such as credit, market, operational and liquidity risks. However, given the unique characteristics of such risks, the principles and methodologies of the current regulatory framework might only take climate risks, including their systemic aspects, into account indirectly or to a limited extent.

Emerging evidence on the materiality of climate risks is indicative of its system-wide relevance. The NGFS has highlighted various channels through which climate risks may affect



financial stability (NGFS, 2020b). The second report of the ECB/ESRB Project Team shows that euro area exposures to physical climate hazards are concentrated at the regional level (ECB/ESRB 2021). Materialisation of physical risk is estimated to affect various geographies in which up to 30% of banks' current corporate exposures are located, with potential stranding risks. Existing vulnerabilities in the financial sector can potentially amplify the impacts of physical risks, the impact of the different physical risks drivers on firms' activities is not yet fully understood, which adds to the difficulty of assessing potential damages to the financial sector. As for transition risks, the exposures of euro area banks to high-emitting firms appears to be concentrated in certain sectors of activity (the "exposure dimension" of climate-related systemic risks). In addition, these exposures are concentrated in some firms suggesting that exposures to high-emitting firms are concentrated not only between, but also within economic sectors. Section 2 highlights that while banking sector loan-weighted emissions to non-financial companies declined since 2015 due to lower sectoral emissions and portfolio shifts to less emitting sectors, they remain tilted towards sectors with higher emission intensity across countries. Moreover, a potential future materialisation of climate risks could be amplified by spill over and second-round effects. When occurring on a widespread basis, this could further strengthen systemic risks.¹⁰⁷

The time dimension and path dependency of climate-related financial risks can fuel the build-up of systemic risks for the banking sector. The scenarios proposed by the NGFS highlight how the transition to a green economy depends on public policy action and the development of new technology. Insufficiently timely or effective climate transition could lead the economy into a disorderly transition or a hot-house world scenario. It is predominantly the responsibility of public policy to adapt to climate change. However, the effect of policy action with respect to climate change is time-delayed. An insufficiently orderly transition to a green economy may translate into significant losses for the banking sector on exposures related to high-emission firms and to exposures vulnerable to climate hazards. Intensified policy and regulatory actions to foster a transition to a net zero economy will reduce the financing of carbon-intensive activities over time but could again fuel the build-up of systemic risks: this time with respect to "runs on non-green, carbon-intensive sectors" or "green bubbles".

Non-bank financial sector and markets

Specific aspects for non-bank financial entities and financial markets with potential systemic implications are relevant to the development a macroprudential approach. Like banks, insurers face risks on the assets side, but also have specific risks related to their liabilities when they are exposed to the effects of climate-related risks in their underwriting portfolios. Investment funds and markets are subject to liquidity risk which can be amplified via standard channels, such as direct interconnections, common exposures and, portfolio correlations. In the absence of clear standards and external verification, greenwashing risk can pose an additional risk in financial markets.

Insurers face exposure to physical risks on the liability side of their balance sheets through insurance contracts, alongside transition and physical risks on the asset side. Climate

¹⁰⁷ See also ECB (2021) and Sections 2.3.2 and 3.5 in this report.



change is expected to further increase the frequency and severity of extreme weather events, such as floods, windstorms and wildfires, which would result in higher claims for insurers that are exposed to physical risk. This mostly affects non-life insurance and reinsurance, where damage to insured property might increase, but also e.g. business interruptions or claims related to hail, such as vehicle or crop insurance. Life insurance business (including health) could still be affected for example, by an increase in heat waves, increasing mortality or health claims. Moreover, the increasing risks are likely to be accompanied by greater uncertainty surrounding the assessment (estimation) of such risks, as historical data may become less relevant for such assessments amid the evolving environment and could complicate the appropriate pricing of policies. When insurers compete in an environment where historical data is of limited relevance, insurers that underestimate the impact of climate change will probably make the most attractive offers, and their market share might increase. If this becomes a widespread phenomenon, there may be systemic implications. The regulatory framework has to ensure that climate change-related risks are appropriately reflected and priced, incorporating forward-looking aspects.

In these scenarios, the underwriting risk for insurance undertakings would increase or the availability and affordability of insurance would be affected. Through the usually annual repricing of non-life insurance contracts, insurers can adjust the prices of contracts should if the risk changes. There are, however, limits to re-pricing and, even where re-pricing is possible, insurance coverage could become unaffordable for policyholders. To prevent the widening or creation of protection gaps, the development of new insurance products is key, as are risk-based adjustments to the design and pricing of the products to include prevention measures aimed at reducing losses, as described according to the concept of impact underwriting (EIOPA, 2021b).

Climate risks may amplify the systemic vulnerabilities of investment funds as the transition to a greener economy advances and certain assets become stranded, with implications for the ongoing work on advancing the macroprudential framework for this sector. On the path to a net zero economy, investment funds might suffer a decline in the value of assets under management if they own a significant share of stranded assets, coinciding with financial losses in other parts of the financial system due to common exposures. This phenomenon could, in turn, trigger significant outflows on the part of investors and further price dislocation in stranded assets and, potentially, in non-stranded assets. Climate-related financial risks (CRFRs) might also amplify liquidity transformation if stranded assets become less liquid. The current absence of forward-looking targets and clear transition paths of most funds investing in highly polluting industries may be another factor driving investors concerned by their environmental impact to redeem from such funds. To the extent that these risk drivers amplify vulnerabilities associated with system-wide liquidity mismatch and interconnectedness, this would be relevant in ongoing European and international work on addressing systemic risks and developing a macroprudential approach.

The potential materialisation of greenwashing risks, triggering the withdrawal of investors from financial products perceived to be green, highlights the importance of establishing sound and robust standards and labels for these products. Indeed, if investments in green financial products, e.g. funds and bonds, turn out to be less green than promised, the materialisation of greenwashing risks¹⁰⁸ may lead to significant and immediate outflows from such

¹⁰⁸ According to the EU Commission's July 2021 strategy, greenwashing can be defined as "The use of marketing to portray an organisation's products, activities or policies as environmentally friendly when they are not".



funds and selling pressure on bond markets. It may also result in reputational damage for connected firms and litigation risk. The proliferation of different industry standards could result in a cliff effect in the market, entailing significant repricing of green bonds when investors perceive that some of them of unsatisfactory quality. Financial risks may also arise from green projects, particularly those aimed at developing highly innovative technologies to achieve decarbonisation.¹⁰⁹

Ongoing European and global initiatives should help to close the data gaps on forward-looking information which remain in climate reporting. In the corporate sector, climate-related disclosures have improved and are expected to increase further over the coming years, thanks to a range of international initiatives such as the EU's CSRD and the International Sustainability Standards Board (ISSB) of the IFRS to enhance disclosure requirements. The assessment of systemic risks stemming from climate change would benefit significantly from the availability of exposure metrics capturing the transitional nature of climate-related risks. This would result in significant improvements in the consistency, granularity and reliability of forward-looking information disclosed by firms, including emission reduction targets and net zero commitments.

4.2.2 Policy interplay and coordination of macroprudential policy

Macroprudential policies will depend on, and interact with, public policies designed to limit and adapt to climate change. The magnitude and timing of the materialisation of transition and physical risks both depend on when and how public policies designed to reduce greenhouse gas emission and adapt to climate change will be enacted. For example, any lack of timely public policy action may increase the financial system's exposure to both (disorderly) transition and physical risks, in turn requiring additional resilience building, including via macroprudential policy (the "time dimension" of climate-related systemic risk). Within the broader realm of public policy to mitigate and adapt to climate change, macroprudential policies cannot substitute actions which directly address climate change itself. This notwithstanding, macroprudential policies, like other regulatory measures addressing climate risks, may also have an effect on the economy-wide build-up of climate risks by, for example, reducing financial institutions' financing of activities not aligned with the transition to a net zero economy, thereby helping to mitigate climate change (double materiality).

Since climate issues may have far-reaching impacts, global and EU coordination in addressing systemic CRFRs is paramount. Developing standards at the international level is warranted. As climate risk is global in nature and likely to materialise as a common shock, consistency in tools and requirements is needed. Macroprudential policy will have to also deal with cross-sectoral and cross-border issues in order to avoid arbitrage and waterbed effects, especially due to the universal nature of climate change. In particular, the increase of transition risks is likely to occur in a correlated across countries, although the magnitude of the exposures to these risks could vary between Member States, depending on factors such as the presence of certain industries, policies and the energy mix. Physical risks will probably increase these correlations, but

¹⁰⁹ The International Energy Agency (IEA, 2021) projects that, in 2050, almost 50% of CO2 emissions reductions in the net zero scenario will derive from technologies currently in the demonstration or prototype stage (see [International Energy Agency: Net Zero by 2050. A Roadmap for the Global Energy Sector](#)). Coupled with their inherent technical complexity, this increases the risk of green innovative projects.



also depend on geographical characteristics, including cross-border ones. Direct and indirect interconnectedness between financial institutions may amplify these risks. Overall, macroprudential policy would therefore be most effective and efficient if it takes a comprehensive perspective that encompasses both the banking and non-banking sectors.

The development of guidelines by the relevant European supervisory authorities (ESAs) or of recommendations by the ESRB may be helpful in fostering consistent implementation and shared understanding of existing and potential future instruments. General guidance could be issued, for example, to specify how climate-related risks fit into intermediate macroprudential objectives and which tools can be used to address systemic risks stemming from CRFR. This could be done, for example, by updating the ESRB handbook on operationalising macroprudential policy in the banking sector.

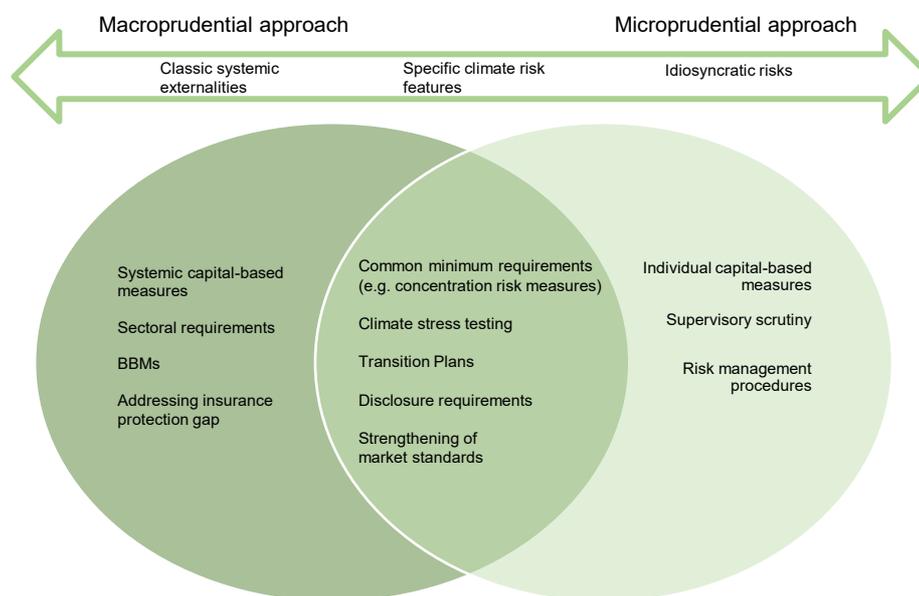
Moreover, to coordinate the use and activation of tools in the EU, the issuance of ESRB Recommendations could be considered, given the system-wide, cross-border and cross-sectoral issues involved. The ESRB could issue recommendations to the EU as a whole, to the ESAs, to the Commission or to Member States, potentially also in relation to specific instruments. The ESRB is currently actively involved in examining the impacts of climate change on financial stability in the EU, and its role is limited to raising awareness of the CRFRs. Within the EU, coordination would also be necessary in developing and using top-down macroprudential stress tests as tools.

Macroprudential authorities considering taking measures should look at existing risk-mitigating policies and recognise the interactions and trade-offs with these as well as the importance of announcement effects. Authorities should consider microprudential requirements and coordinate with microprudential authorities before taking steps where applicable. A close dialogue will be needed between micro- and macro- prudential authorities to ensure the most effective and coherent set of policies to mitigate climate-related risk. For example, the activation and calibration of macroprudential tools should take into account whether and to what extent climate risks are already addressed from an idiosyncratic perspective through the prudential framework, including through possible future Pillar 2 measures in the supervisory review and evaluation processes (SREP), and vice versa. Moreover, some measures may form part of both a macroprudential and microprudential approach to climate risks (see Figure 9). The interaction of macroprudential policy with crisis management and financial safety should also be considered. In this context, Box 8 provides initial considerations of how CRFRs affect EU crisis management and financial safety nets for banks and insurers. Careful monitoring of financial institutions' (collective) behaviour in response to risk developments and the micro- and macroprudential and broader policy measures taken, will be of key importance here, and such monitoring would also need to be coordinated. Lastly, announcement effects may be a relevant consideration when considering the case for, and interaction of, macroprudential and microprudential policy levers, some of which are published, while others are not publicly disclosed.



Figure 9

Measures under micro- and macroprudential approach to climate risks



Source: ECB. Notes: This figure is for illustration purposes and not meant to be comprehensive

Box 8

How do climate-related financial risks affect EU crisis management and financial safety nets for banks and insurers? The practical case of resolution

I. Banks

The EU's resolution framework provides the necessary powers, tools and procedures to deal with the failure of banks in an orderly manner, with the aim of preserving financial stability, ensuring the continuity of critical functions and protecting depositors' and taxpayers' money. While Section 4 discusses how prudential tools could be adapted to, and affected by, climate risk, this box explores the interactions between climate risk and the resolution framework and how the latter, within its mandate and general objectives, could help to supporting the transition to a carbon-neutral economy.

The financial system needs withstand shocks posed by climate-related risks and, at the same time, be part of the solution, by influencing sustainability factors (double materiality principle). From a going concern perspective, banks and resolution authorities could enhance preparedness for recovery and resolution by incorporating climate-related considerations and risks into planning and resolvability assessments (for institutions with resolution strategies). This may entail, among other things, an analysis of institutions' exposures to non-green, carbon-intensive activities and sectors. The resolvability assessment may be a good vehicle for capturing climate-related bank-specific impediments to resolution and devising actions to remedy or mitigate those risks. In turn, banks



would also need to incorporate climate-related considerations and risks in their recovery planning and when assessing their own resolvability in line with the expectations laid down by the resolution authorities. From a gone concern perspective, similar considerations may be warranted regarding the obligation to reorganise the business model, post-resolution, which could also include a requirement for the bank to improve its sustainability: for example, by reducing its carbon footprint and by greening its financing policy. Such a reorganisation might also help to ensure that the resolved entity is compliant with European sustainable finance rules.

The resolution framework should also be fit for purpose in a climate-driven failure. In principle, the existing framework and its resolution powers and tools are able to handle bank failures, regardless of from the origin of losses, including the materialisation of climate risks. Indeed, resolution tools, such as, for example, the transfer of green assets to an acquirer through the sale of business, or to a bridge bank, or the winding down of stranded assets via an asset management vehicle, could be used in the event of a climate-induced failure. The objective of the minimum requirement for own funds and eligible liabilities (MREL) is to ensure loss absorption and, where the strategy requires this, recapitalisation of the bank in resolution. Assuming that climate-related risks are captured by the prudential framework, they would indirectly affect the calibration of the MREL requirements for banks, as these requirements are based on their capital requirements in terms of total risk exposure amount (TREA) and the total exposure measure for the leverage ratio. The implications of bailing in liabilities underpinning green or non-green, carbon-intensive assets may also provide an interesting angle of analysis, which could be explored further.

The consistency between the objective of the MREL requirement, which is to provide loss absorption and recapitalisation capacity, as a first line of defence, and its eligibility as green/sustainability-linked bonds, could be analysed further. The resolution authority's power to bail-in instruments during resolution is not dependent on the sustainability level of the respective instruments, but rather driven by clear eligibility criteria designed to ensure bail-inability and the obligation to accomplish the resolution objectives most effectively (safeguarding financial stability and avoiding contagion, preserving critical functions and mitigating the risk of recourse to public funds). While in the EU, there is no prohibition on considering TLAC/MREL bonds as green bonds if they comply with the respective eligibility criteria, other jurisdictions (Switzerland) do not allow TLAC bonds to count as green. Acknowledging the differences between the objectives of the bail-in tool and that of ensuring sustainable financing of the economy, EU regulators, supervisors and resolution authorities should monitor these interactions further¹¹⁰.

The climate-conscientious management of financial safety nets such as the deposit guarantee schemes (DGSs) or the Single Resolution Fund (SRF) would enhance their sustainability. Climate risks could be taken into account in the investment strategy and fund management activities of DGSs and the resolution funds (the Single Resolution Fund (SRF) in the banking union and national resolution funds outside the Banking Union) to incorporate a “do no harm” principle. Moreover, climate change may pose operational risks to the infrastructure of DGSs and resolution funds and their respective core activities and ability to safeguard timely pay-outs.

¹¹⁰ See also EBA (2021).



Insurers

Similar reflections could also be made regarding the recovery, resolution and financial safety nets applicable to insurers. With regard to resolution, the Commission has recently proposed an EU harmonised recovery and resolution framework for insurers. The proposed framework sets out the recovery and resolution planning requirements and equips authorities with a resolution toolkit, to address failures of insurers, in an orderly manner, which are similar to those available for banks but tailored to the specificities of the insurance sector. Therefore, the considerations regarding the potential need for adjustments of the resolution framework (in terms of planning/resolvability assessments) to cater for CRFR are also relevant for the forthcoming EU insurance recovery and resolution framework. In contrast to banks, the proposed framework for insurers does not require the build-up of a minimum loss-absorbing capacity (i.e. similar to the MREL) or mandate the use of external funding in resolution (i.e. in the form of contributions from financial safety nets such as resolution funds or insurance guarantee schemes (IGSs)), while, at the moment, there is no harmonised EU framework for IGSs. Therefore, under the Commission's proposal, the use of financial safety nets to protect policyholders and potentially support resolution actions, is left at national discretion. In any event, the same considerations applicable for the financial safety nets for banks (operational risks, investment and fund management risks) are also relevant for the existing national resolution funds or national IGSs that are available in the Member States to handle failures of insurers.

4.3 Considerations regarding potential macroprudential policies

In this section, we provide conceptual considerations that could help identify policies to effectively address the systemic aspects of climate risks. Distinguishing between banks, non-bank financial entities and markets, we discuss the suitability of candidate policy tools and provide considerations from a macroprudential perspective for potential future changes to the existing framework, recognising the existing rules targeting climate risks. Furthermore, we discuss potential enhancements of disclosure rules, including for non-financial entities. All of this work builds on, and also feeds into, European and international initiatives in the sphere of prudential policy (see Annex 2 for a summary of ongoing and past initiatives).

4.3.1 Potential macroprudential measures for the banking sector

This section provides considerations on the suitability of both existing and new macroprudential policies for addressing climate-related risks to the banking system. We have analysed several tools that could be employed to address systemic aspects of climate risks for the banking sector. Table 13 sets out these potential tools alongside their main policy objectives and ranks the relative desirability of each option. In particular, tools with a relative strong rationale are marked in green, tools that are considered with a more neutral rationale are marked in orange and tools considered less suitable are marked in red.



With none the of the existing instruments being readily deployable to address climate risks, adaptations of these instruments and/or the development of new tools will be needed. Some adaptations can be accommodated with a change in guidelines or implementation standards, some of which will be easier and faster to implement than others. Some would require such a substantial change in the legislation, possibly also inconsistent with the purpose or spirit of the original instrument, suggesting that the introduction of a new specific instrument could have advantages.

Macroprudential measures need to be seen in the context of a holistic prudential approach to climate risk. A holistic approach, involving commonly applied Pillar 1 measures, would help to ensure a certain degree of consistency to tackle a global risk such as climate change. The available data and methodological constraints suggest that more work is required to effectively revise the current framework in order to fully capture the unique features of climate risks. In this context, macroprudential policy can address the systemic features of climate risk and should aim to complement Pillar 2 (e.g. specific issues stemming from concentrated exposures could be addressed by increasing the overall resilience of the system with macroprudential buffers). Table 13 lists a range of potential measures.¹¹¹ While not all measures are needed, a macroprudential approach has to be sufficiently flexible for risks such as those stemming from climate change, the impact of which is very uncertain.

The SyRB, in its sectoral application, could be used to contain the build-up of risk concentration, and at the same time enhance the resilience of banks against the materialisation of climate risks. In the draft Banking Package 2021 the EU Commission clarified that the sectoral application of the SyRB could also already used for “certain sets or subsets of exposures, for instance those subject to physical and transition risks related to climate change”. Therefore, the sectoral use of the SyRB may be an adequate tool to discourage concentrated exposures, as concentrations may occur in terms of both banks exposed to, and sectors most vulnerable to, climate risks (cf. chapters 2 and 3) and may also incentivise banks to adapt their balance sheets. Moreover, it would imply higher capital requirements and therefore increase banks’ resilience against the materialisation of climate risks. This positive impact on resilience would need to be weighed against any negative side effects, and its application should avoid material unintended consequences. For example, a phase-in period may be considered to avoid any abrupt deleveraging in carbon-intensive sectors. Moreover, the heterogeneity of firms within sectors would need to be duly assessed. Before applying the tools, some (limited) adaptations may be needed. First, a more differentiated definition of sectoral subsets in the EBA guidelines based on a common classification system of what can be considered environmentally harmful/friendly sectors may be needed. Second, due to the global nature of climate-related risks, an extension to foreign exposures currently not within the scope of the SyRB may be warranted when applied in this context.

¹¹¹ Some of the measures listed are of hybrid nature, i.e. they would be both part of a Pillar 1 approach and a macroprudential approach to address climate risk. See also Figure 9.



Table 13

Candidate tools for addressing climate-related systemic risks in the banking sector

Options	Intermediate Policy objective (ESRB/2013/1)	Status	Possible application	Selected helpful attributes	Selected drawbacks
(Sectoral) systemic risk buffer (SyRB)	Increase resilience, limit concentration (for sectoral application)	Adaptations needed (limited)	Increase resilience against materialisation of risks from such exposures Discourage exposure to certain geographical areas for physical risk and/or carbon critical "sector" for transition risk;	Very flexible	Challenging calibration, complex classification system of sectors/geographical areas exposed to climate risk (for sectoral application), currently applicable for domestic exposures only
Concentration threshold	Limit concentration	Adaptations needed	Non-capital-based measure to limit exposure to a certain geographical area for physical risk and to a certain carbon critical "sector" for transition risk	Targeted measures	Challenging calibration, complex classification system of sectors/geographical areas exposed to climate risk
Concentration charge	Increase resilience, limit concentration	New tool	A risk-weighted capital add-on that applies once exposures to a certain sector or geographical area particularly exposed to climate risk exceed a certain threshold.	Targeted measures	Challenging calibration; complex classification system of sectors/geographical areas exposed to climate risk
Sectoral requirements (risk weights or minimum LGD)	Increase resilience	New tool Or Adaptations needed	Higher risk weights or minimum LGD could be required on exposures to high physical and/or transition risk.	mandatory reciprocity (limits arbitrage)	New complex tool, challenging calibration, impact on microprudential requirements
Sectoral leverage ratio	Increase resilience	Application not yet possible at sectoral level	Avoid over-leveraging of sectors or regions that are highly exposed to transitional or physical risks	Sectoral approach could allow targeted increase in resilience	Would make the tool more complex and risk-sensitive, would deviate from its general function as non-risk-based backstop
Capital conservation buffer (CCoB)	Increase resilience	Adaptations needed, recalibration of current 2.5% level needed to include climate risk	An add-on to the existing CCoB could be explored to build resilience against unexpected exogenous tail events related to climate risk	Create additional resilience	Non-targeted measure, adaptations challenging
Countercyclical Capital buffer (CCyB)	Increase resilience, prevent build-up of risks	Adaptations needed	Buffer add-on during periods of excessive carbon-intensive credit growth	--	Cyclical nature of climate risk unclear, design changes needed, challenging calibration and application, overlap with sectoral SyRB



Options	Intermediate Policy objective (ESRB/2013/1)	Status	Possible application	Selected helpful attributes	Selected drawbacks
Borrower based measures (BBMs)	Prevent build-up of risks	Adaptations needed (to a varying degree)	Could decrease vulnerability of households towards aspects of climate risks and change the pattern of demand towards more energy efficient houses or houses located in geographical areas less prone to physical risks (if applied in mortgage markets)	Very flexible, no additional capital	Gradual effect on resilience, targeting only specific portfolios, politically more sensitive
NSFR-LCR	Prevent market illiquidity	Inclusion of climate-specific aspects would require adaptations	Could cover risks related to sudden repricing in financial markets	--	Need for distinct climate features unclear
Systemic bank buffers (G-SII/O-SII)	Misaligned incentive	Inclusion of climate specific indicators would require adaptations	Could cover bank-specific risks, for systemic institutions	--	Climate risks are not specifically related to systemic importance of individual institutions.

The SyRB, not distinguishing between sectors, is already part of the existing macroprudential toolkit and could be used as a general tool to guard against systemic aspects of climate risks not necessarily linked to the concentration risk of individual institutions. The SyRB aims to address systemic risks that are not covered by the Capital Requirements Regulation or by the CCyB or the G-SII/O-SII buffers (ESRB, 2022). By avoiding a distinction between sectors, applying this tool is likely to be less challenging than applying a sectoral SyRB. Finally, a flat SyRB could be envisaged to address unexpected exogenous shocks, including climate-related ones, making it a suitable tool for dealing with the risk of severe exogenous shocks. Such a buffer, once released, could help to maintain a steady flow of lending to the economy and prevent an amplification of the initial shock in such a tail event. As a potential alternative, a new releasable climate risk buffer is worthy of further consideration, in case it is preferable to have a separate buffer targeting climate risk.

Concentration thresholds may incentivise banks to reduce the concentration of their exposure to carbon-intensive sectors (transition risks) or to geographical regions exposed to physical risks. Such thresholds would take the form of a non-capital-based tool targeting concentrated exposures above certain thresholds. While Article 458 CRR already permits the setting of tighter large exposure (LE) thresholds for macroprudential purposes, the current requirement limiting LE is meant to address risks from large exposures to one single customer or a group of connected customers focusing on concentration from an idiosyncratic risk perspective. However, the requirement limiting LE does not take into account the interconnectedness of



counterparties based on sector activity, emission intensity or geographical area. Adapting the existing LE regime and allowing more flexibility in the current framework would be one option for the implementation of concentration thresholds. A second option may therefore be the introduction of such a concentration threshold outside the large exposure regime, aimed at counterparties significantly exposed to common climate risk shocks.

Further assessment, both to identify relevant counterparties and to design a climate concentration threshold, could be envisaged. Identifying the appropriate set of counterparties in scope would require a thorough analysis, building on existing data (e.g. emission data for transition risks), to ensure the proper classification of relevant exposures. The new tool could be applied in a harmonised way across EU jurisdictions and it may be more effective for the long-term nature of climate risks (compared with Article 458 which foresees a two-year time limitation, although with for the possibility of extension). It could be designed so that the breaching of certain thresholds for relevant exposures triggers supervisory scrutiny and/or requires banks to explain how they will address concentration risks, making it a non-capital-based tool. Indeed, a breach of the threshold could trigger intensified supervisory scrutiny and a process in which banks would be required to come up with a plan to adequately address the risks stemming from the exposure breaching the threshold, also taking into account transition plans (e.g. to avoid any unintended consequences for the financing of the transition of current high emitters). The data needed for the tool could also be aligned with the disclosure requirements to the maximum extent possible, to lessen the operational burden on the institutions.

Concentration charges would represent a completely novel tool for addressing climate-related concentration risks by requiring additional capital for exposures beyond certain thresholds. In practice, a risk weight add-on – also referred to as a coefficient or a charge – could be applied to relevant exposures above a certain threshold, thus increase the RWA of the bank. The charge could increase stepwise with higher concentrations, in order to avoid cliff effects. By increasing the RWA, the concentration charge (or charges, if a stepwise approach is taken) would affect all calculations of the capital framework, raising capital requirements overall. A careful assessment of potential negative side effects, the potential overlap with microprudential requirements and consequent double counting and the implications for the complexity of the capital framework would be required.

New sectoral requirements for risk weights or LGD similar to existing tools targeting the real estate sector could be analysed. Higher risk weights or minimum LGD could be investigated for exposures to high physical and/or transition risk. This could represent a targeted approach to account for the risk differential between sustainable and non-sustainable assets. However, establishing such general risk differentials could prove to be very challenging. Any changes to these fundamental inputs to the risk-based approach could have a broad, material effect and therefore would need to be properly justified.¹¹² Moreover, at the current stage, measures for LGD would apply to banks using the internal ratings-based (IRB) approach only, thus excluding a significant part of the banking system.

¹¹² For example, the NGFS found that there is still limited empirical evidence of risk differentials and conducting risk differential analysis is not a straightforward exercise (See NGFS (2022)).



A sectoral use of the leverage ratio would place a limit on the amount of leverage used to finance assets more exposed to climate risk but might undermine the role of the ratio as non-risk-based backstop. A sectoral leverage ratio buffer applied to exposures relevant from a climate risk perspective would represent a new tool requiring a change in legislation. While this would imply an increase in the resilience of financial institutions, such a buffer could be regarded as a risk-based tool, running counter to the general role of the leverage ratio as a non-risk based backstop.

Adding a component on top of the existing CCoB could be explored, in order to build resilience against unexpected exogenous tail events related to climate risk, but the necessary adaptations could prove challenging. Adding such a component on top of the existing CCoB would however require substantial changes to the existing framework, increasing its complexity. Moreover, it is unclear whether adding such a component would make any significant difference to the overall resilience of the banking sector in the event of a disruptive tail event related to climate risk.

While the CCyB could, in principle, be redesigned to account for the cyclical features of climate risks, there is currently limited evidence of such features. A dedicated treatment could extend the CCyB in its current form to address climate risks. For instance, the introduction of a buffer add-on for carbon-intensive loans during periods of excessive carbon-intensive credit growth could be considered. However, the CCyB does not seem to be particularly well-suited to addressing environmental risks, given that environmental risks are mainly structural and non-cyclical risks that tend to accumulate over time. Also, the primary indicator for the calibration of CCyB is the credit-to-GDP gap, and substantial changes to the methodology may be required to account for climate risks.

BBMs could help to address climate risks at the loan level but are subject to several important design and implementation challenges. Climate risk may affect both the collateral value as well as the solvency of borrowers and hence both the loss given default of the loan and the probability of default of mortgage borrowers. In this context, stricter (looser) BBMs could be applied for mortgages based on properties that are more (less) exposed to physical and transition risks, mitigating the impact of climate risks on leverage or the repayment capacity of borrowers. For instance, stricter LTV/DSTI/DTI/maturity limits could be defined for less energy-efficient houses, or for houses that are particularly exposed to physical risks, such as floods. BBMs have the advantage of being very flexible and might be particularly effective in inducing behavioural change towards a greener economy. Moreover, these measures are targeted and require no additional capital. At the same time, a further exploration of such measures would need to consider several drawbacks of such measures. First, given that BBMs generally apply to new loans for households only, their effect on climate risks building in the overall stock of loans may take time to materialise. In addition, such measures would have a political dimension as other BBMs and would require evidence of risk differentials between sustainable and non-sustainable activities, and face a risk of heterogeneous application across jurisdictions. Finally, since the application of BBMs has been limited to residential real estate loans and households, exploring ways of applying BBMs to commercial real estate loans and loans taken by legal persons would be needed to mitigate the climate-related risks effectively and to avoid risk shifting between sectors.



Further work to understand whether introducing climate-specific rules for liquidity requirements is needed.

The LCR in its current form is designed to help banks to deal with episodes of market illiquidity. While the sudden materialisation of transition risk may indeed trigger such episodes, it is unclear at this stage whether any climate-specific amendments are needed. Further work would be required if specific adaptations are needed. Similarly, further analysis would be required to establish that the net stable funding ratio (NSFR) would need to specifically account for climate risk. For example, one would need to establish that there is a significant difference in the funding profile for assets more exposed to climate risk compared with others.

A G-SII and O-SII buffer adapted to climate risks may be envisaged but it is unclear whether climate risks imply additional moral hazard concerns for systemic banks.

The methodology used to identify banks' systemic importance is based on indicators that are not specifically related to climate risks. Adding a climate component to the G-SII or O-SII buffer methodology may then provide additional resilience linked to the systemic importance of a bank. However, it is unclear at this stage whether climate risks are increasing the systemic importance of banks and whether climate risks imply additional moral hazard concerns for systemic banks that may motivate such a change in the methodology.

Additional considerations can be drawn on the basis of policies considered in other countries, including the United Kingdom and Canada.

The Bank of England and the Prudential Regulation Authority have tabled a proposal for an "escalating" climate buffer, which is based on a risk assessment on the materiality of future system-wide transition and the physical risks associated with climate change. Canada's top financial regulator is considering requiring a build-up of capital buffers in order to ensure that federally regulated financial institutions can endure an abrupt transition to a green economy. Existing proposals discussed in the Canadian parliament include the definition of "one-for-one" capital requirements for the funding of new fossil fuel projects, which would require banks to fund these projects with own funds.

Generally, when applying measures that are justified from a macroprudential perspective, careful consideration should be given to potential unintended consequences, interactions with other climate policies as well as the consistency with the broader regulatory framework.

Informing the design and calibration of macroprudential measures using data and information already available due to climate risk related reporting and disclosure requirements would help to ensure that any new measure would appropriately target relevant risks and be consistent with the risk-based prudential framework. When designing new measures, it is also important to be mindful of potential undue favouring of environmentally friendly assets to avoid both a lack of appropriate coverage against potential losses from such exposures and any contribution to the build-up of "green" asset price bubbles. The interaction with other policies, like banks' transitions plans and microprudential measures, would also need to be closely analysed (see also Section 4.2 on coordination of macroprudential tools). Finally, further work would be required to understand whether systemic aspects of climate risks require additional capital, and whether benefits to building resilience outweigh potential costs.



4.3.2 Macprudential policy considerations regarding disclosures, the non-bank financial sector and financing the transition

Building on existing and forthcoming regulatory provisions addressing CRFRs, this section provides considerations on possible further amendments to the regulatory framework from a macroprudential perspective. Across the non-bank financial sector and financial markets, a range of rules on CRFRs have been already included in regulation. Focusing on investment funds, insurers, pension funds and bond markets, Annex 2 aims to identify the existing and forthcoming revisions to the regulatory framework that are most relevant from a macroprudential perspective. This section starts with considerations on the potential enhancements of disclosure rules that would support the assessment of systemic risks stemming from climate change. It also develops a few ideas for further amendments to the regulatory framework that would help to address systemic aspects of CRFRs for non-bank entities and financial markets from a macroprudential perspective. Lastly, the section discusses both the insurance protection gap and the investment gap given their important system-wide implications for CRFRs, although the required policy response to these gaps is largely in the area of public policy as opposed to macroprudential policy.

While existing and forthcoming provisions integrating CRFRs into the regulatory framework will also help to reduce the systemic aspects of CRFRs to some extent for non-banks and financial markets, the special nature of CRFRs may require further measures to fully address these aspects. The integration of sustainability risks into the regulatory framework such as risk management procedures will enhance non-bank's resilience against climate-related risks. Transparency and disclosure rules will help market participants to better judge CRFRs. Nevertheless, as explained in the chapter on the rationale for macroprudential policy, additional measures justified by macroprudential considerations may well be required to fully address the unique features and their systemic implications.

Disclosures

The availability and reliability of climate-related data are core elements in the assessment of systemic risks stemming from climate change. Disclosures are therefore an important part of a macroprudential approach to climate risks. However, key issues remain in terms of the coverage and comparability of the climate-related disclosures of firms and data from third-party providers. The reliability of climate-related information from banks and non-banks eventually hinges on the availability of data from all sectors, including primarily non-financial corporates.

The current European disclosure framework on ESG risks builds on several pillars: first, the Non-Financial Reporting Directive (NFRD) ¹¹³ is the principal framework for disclosures on CRFRs. Second, information on ESG risks and risk mitigation actions are part of the prudential disclosure

¹¹³ **Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups** (OJ L 330, 15.11.2014, p. 1).



for large listed banks (Capital Requirements Regulation - CRR¹¹⁴) and investment firms (IFR)¹¹⁵. Third, the Sustainable Finance Disclosure Regulation (SFDR) requires disclosures for manufacturers of financial products and financial advisers toward end-investors.

Going forward, the proposed CSRD will harmonise and expand the disclosure requirements, in relation to both the companies in scope and the items to be disclosed. The Directive is expected to cover more than four times the 11,000 companies covered by the NFRD. The share of total turnover covered will increase from 47% to 75%, and the share of listed companies that report will increase from 41% to 81% (European Commission, 2021d). Regarding the data disclosed, the proposed CSRD explicitly states that the sustainability report must include forward-looking, retrospective, qualitative and quantitative information in the short, medium and long term. The content of the standards is being developed by the European Financial Reporting Advisory Group (EFRAG, 2022), while the data disclosed will be machine readable and feed into a proposed European Single Access Point (ESAP).

Forward-looking metrics and disclosures are a key element in the assessment of CRFRs and have been identified as a major data gap for financial stability analysis (ECB/ESRB 2021, NGFS 2021). As well as past climate performance, forward-looking disclosure is essential to understand the extent to which the climate performance of a firm is compatible with the Paris Agreement's objectives, to estimate potential future losses due to exposure to climate-related risks and to describe the actions planned to mitigate climate risks. It can improve market pricing and transparency, thereby reducing the potential for large, abrupt corrections in asset values that can destabilise financial markets and affect financial stability as a whole. Forward-looking disclosures include setting long-term targets (e.g. emissions reduction targets), defining opportunity metrics to reach a target (e.g. expected capital or R&D expenses associated with an adaptation plan), and estimating future exposure and risks (e.g. expected losses due to exposure to transition or physical risks given a climate scenario, climate value at risk). Most forward-looking metrics rely on scenarios or hypotheses regarding future variables (e.g. emissions, temperatures, etc).

One of the main challenges of the forward-looking information currently available is its heterogeneity, in terms of the information disclosed, the methodologies used, and the reliability of disclosures. Due to the lack of uniform and binding disclosure standards, forward-looking information disclosed by companies is very difficult to compare and aggregate. On the basis of a survey of existing international standards and a sample of European corporate reports, firms disclosing forward-looking metrics may rely on different climate-related scenarios (e.g. the NGFS or Intergovernmental Panel on Climate Change (IPCC)) and emissions pathways (national vs. global); they may refer to different time horizons, base or target years, and scope of data (e.g. scope 1/2/3 emissions, absolute emissions vs. emission intensity). Methodologies used to calculate similar types of metrics (such as climate value at risk or portfolio alignment tools) can rely on very different

¹¹⁴ Regulation (EU) No 575/2013 of the European Parliament and of the Council of 26 June 2013 on prudential requirements for credit institutions and investment firms and amending Regulation (EU) No 648/2012 (OJ L 176, 27.6.2013, p. 1).

¹¹⁵ Regulation (EU) 2019/2033 of the European Parliament and of the Council of 27 November 2019 on the prudential requirements of investment firms and amending Regulations (EU) No 1093/2010, (EU) No 575/2013, (EU) No 600/2014 and (EU) No 806/2014 (OJ L 314, 5.12.2019, p. 1).



modelling assumptions and estimation techniques, leading to divergences in results¹¹⁶. As emphasised by the Task Force on Climate-related Financial Disclosures (TCFD)¹¹⁷, there is a lack of transparency in forward-looking disclosures, as the methodological choices underpinning metrics and targets are not always disclosed, often with a view to minimise decarbonisation efforts.

Agreement on a set of key standardised forward-looking metrics and targets, combined with the provision of reference climate scenarios and methodologies, will be necessary to improve the quality of forward-looking disclosures. Table 14 summarises some of the key forward-looking exposure and risk metrics (see the Annex for a list of climate-related forward-looking metrics). Regarding transition risk, key exposure metrics include the disclosure of emissions reduction targets in absolute terms for scope 1, 2 and 3 emissions, including interim targets and a detailed description of the plans for their achievement. For financial institutions, targets for financed emissions can be incorporated into portfolio alignment tools to assess compatibility with broader climate objectives. Regarding exposure to physical risks, a key metric is the expected amount of revenue and profits derived from high physical risk locations. With respect to risk metrics, the expected Value at Risk from physical and transition risks would provide valuable information. Other risk metrics include the amount of expected capital and R&D expenses associated with an adaptation plan for transition risk and expected asset damage and insurance costs for physical risks.

Table 14
Summary of key forward-looking exposure and risk disclosure metrics

	Exposure	Risk
Transition risk	<ul style="list-style-type: none"> Emissions targets (scopes 1,2 and 3) in absolute terms incl. interim targets and plans (NFCs) Portfolio alignment (FIs) 	<ul style="list-style-type: none"> Expected capital and R&D expenses associated with an adaptation plan (NFCs) Expected Value at Risk (FIs and NFCs) Expected PD (EL) and LGD change due to transitional risk (FIs)
Physical risk	<ul style="list-style-type: none"> Expected amount of revenue/profits from high physical risk locations (NFCs) 	<ul style="list-style-type: none"> Expected Value at Risk, expected asset damage and insurance costs against physical risks (FIs and NFCs) Expected EL and LGD change due to physical risks (FIs)

To improve the comparability of key forward-looking metrics, public sector guidance appears essential. Such guidance may take the form of guidelines on GHG emissions accounting (especially Scope 3), and the provision of granular climate risk scenarios. These scenarios would include transition paths (emissions and GDP changes by economic sector and region) as well as physical risk heat maps based on recent scientific findings. Furthermore, such public sector guidance may cover how firms could use scenarios and estimation methodologies in their risk assessment framework. Third-party verifications of disclosures could also be systematized to improve the reliability of commitments. The lack of standardised and mandatory forward-looking

¹¹⁶ Bingle et al. (2021), for example, show that a considerable degree of divergence exists between various providers of transition risk metrics. Qontigo, a provider of analytics and indices, compares methodologically similar forward-looking climate metrics for 135 companies from three different data providers and finds a modest positive relationship between the providers.

¹¹⁷ See for instance the summary of the results of the **TCFD forward-looking financial metrics consultation** (March 2021).



information is no longer regarded solely as an ESG issue, but one that has an impact on future global financial stability.

Investment funds, investment firms and financial markets

For the investment fund and investment firm sector, clear classification of funds' investment strategies to address CRFRs reflected in their marketed material is important to avoid greenwashing and help encourage the funding of the transition to a low-carbon economy.

While SFDR disclosures are expected to provide structure and comparability between financial products, a labelling system for investment strategies aligned with disclosure requirements would make it easier for investors to understand and enable them to assess funds' real contribution to transition. The new disclosures templates introduced by SFDR – which will become mandatory from 1 January 2023 – will introduce transparency to investors and standardisation across products. Furthermore, taxonomy-related disclosures will provide comparable additional information regarding the environmental objective pursued and the portfolio's alignment with the taxonomy. Careful monitoring of the implementation of these legislative changes will be necessary, in order to assess the impacts on industry practices. Possible further regulatory action might need to be considered, should the upcoming disclosure requirements prove insufficient to address greenwashing concerns and ensure minimum safeguards for ESG funds.

Additional measures to address the concentration of CRFRs in investment funds and investment firms could be investigated, consistent with considerations on addressing concentrated CRFRs in the banking sector. Previous work by the ESRB-ECB Project Team on climate risk monitoring has highlighted that exposures to climate risk drivers are also concentrated in investment funds. These empirical findings could form the basis of a thorough investigation of the benefits and drawbacks of introducing climate concentration risk measures for this sector targeting exposures to common climate risk shocks. Notably, UCITS funds already have concentration limits for individual counterparties set out in the current regulatory framework under Article 52 of the UCITS Directive.¹¹⁸ However, as it is the case for the large exposure framework for banks, the current requirements do not target sets of counterparties based on sector of activity or geographical area. Such tools could also help prevent the migration of risks from the banking sector to the asset management sector, if they were introduced into the banking regulatory framework. At the same time, in the discussion of the design of such tools, it would be important to give due consideration to their potential negative effects, and the specificities of each sector should be carefully considered when investigating these new tools. Indeed, such tools should not limit funds' ability to finance the transition, conflict with the principle that asset managers should operate in the best interest of their customers or create additional risks (migration risk or undesirable cliff effects).

More generally, the ongoing work to develop a macroprudential approach for the investment fund sector in order to address system-wide liquidity mismatch and interconnectedness should also take CRFRs into account. As CRFRs may amplify vulnerabilities associated with

¹¹⁸ **Directive 2009/65/EC of the European Parliament and of the Council of 13 July 2009 on the coordination of laws, regulations and administrative provisions relating to undertakings for collective investment in transferable securities (UCITS)** (OJ L 302, 17.11.2009, p. 32). According to the **Directive**, these funds should not have more than 10% of their net assets invested in assets issued by the same entity. In addition, when the exposure to a single issuer exceeds 5%, these cumulative investments should not exceed 40% of the fund's net assets.



system-wide liquidity mismatch and interconnectedness, they should be taken into account in ongoing European and international work on addressing systemic risks and developing a macroprudential approach. This would be also consistent with the review of the EU macroprudential framework for banks, where climate risks are also part of the discussion.

In the area of financial markets, a future mandatory standard for green bonds could help to further reduce climate-related risks to financial stability. The proliferation of different industry standards may lead to a cliff effect in the market entailing significant repricing of green bonds when investors perceive that certain green bonds are of unsatisfactory quality. This repricing cascade may affect genuine green bonds if investor confidence is undermined. Establishing a mandatory standard for green bonds could help address these issues. The proposed regulation on European Green Bonds (EuGB) has the potential to allow the market to operate more effectively, to improve the pricing of financial risks and sustainable assets, and to enhance investor confidence in this asset class and mitigate greenwashing. Such an official standard, if well-established in the market and effectively enforced, has the potential to become a quality benchmark in green bond markets and represents an important step in the right direction. It also represents a possible candidate for a future mandatory standard for green bonds, subject to further assessment on the potential effect on the market for green bonds in the EU.

Insurance sector

In line with the reflections on climate risk concentrations in investment funds, similar investigations could take place for the insurance sector. Concentration risk is a part of the standard formula calculation of the solvency capital requirement (SCR) in the market risk concentration sub-module¹¹⁹. It is designed to mitigate losses stemming from a lack of diversification or from a large exposure to default risk of a single issuer or related issuers of securities. Like the regulatory framework for banks and investment funds, the concentration risk sub-module is thus also calibrated on a single name basis. Depending on the type of asset and its credit rating, a capital surcharge is required when an insurer's aggregated exposure to a single name exceeds a certain threshold¹²⁰. This implies that the current regulatory framework requires additional capital for asset concentrations, rather than imposing a concentration limit threshold in the strict sense. Within the limits of their available own funds and in line with the prudent person principle, insurers are thus free to make their asset allocation decisions to ensure a match with the liabilities side. Reflections on any new measures for economic activity-specific or geographical concentration risks would need to take this into account.

The (re)insurance sector could play a key role, not only by transferring and pooling risk, but also by contributing to climate change adaptation through innovative product design and risk-based adjustments to pricing to include prevention measures aimed at reducing losses (impact underwriting (EIOPA, 2021b)). Impact underwriting promotes a risk-based approach for climate-related adaptation measures in insurance products, stimulating policyholders to adopt risk-

¹¹⁹ See also [Commission Delegated Regulation \(EU\) 2015/35 of 10 October 2014 supplementing Directive 2009/138/EC of the European Parliament and of the Council on the taking-up and pursuit of the business of Insurance and Reinsurance \(Solvency II\)](#) (OJ L 12, 17.1.2015, p. 1), Articles 182-187.

¹²⁰ Thresholds between 1.5% and 15% of a given insurer's total assets, see also *ibid.*, articles 185-187 on the related excess thresholds and specific exposures



reducing behaviour. These adaptation measures, e.g. an investment in property-level resistance and resilience to perils such as windstorms, implemented before a loss occurs, can reduce the physical risk exposure of the policyholder and the insured losses for insurers. This could be a key tool in maintaining the availability and affordability of non-life insurance products in the future, while being consistent with actuarial risk-based principles. As these options relate to insurance practices at the individual policyholder level, to have an impact at the macro-level they would need to be applied to a large number of customers and to institutional clients, i.e. companies and local authorities (EIOPA, 2019).

Impact underwriting practices, however, have to be designed carefully, in order to avoid any exacerbation of the protection gap or the risk of greenwashing. More individualised, risk-based calculations of premiums would require a higher degree of information and could cause the administrative costs of the policy to rise accordingly. In addition, adaptation measures might entail higher ex ante costs for policyholders. Furthermore, the lack of common standards to define and measure the contribution of products and services to climate change mitigation and/or adaptation could increase the risk of greenwashing. EIOPA has launched a pilot exercise to better understand how insurers integrate climate-related adaptation measures into non-life insurance products and to assess the appropriateness of the corresponding prudential treatment of these insurance products (EIOPA, 2022b).

Insurers also play an important role in mitigating the macroeconomic effects of catastrophes which may be precipitated by climate change, and public policy action may be needed to support this role. Damage due to natural hazards is set to increase, even in the most benign climate scenario both in Europe and globally, and insurance has a key role to play in mitigating the impact of future catastrophes. Research shows that by accelerating reconstruction and limiting the period of lower output, insurance can help reduce the overall macroeconomic loss (EIOPA, 2021c). Yet the insurance protection gap in Europe is significant and may deteriorate further in the absence of policy intervention, with clear fiscal implications.

The design of insurance policies can address the structural causes of the private insurance protection gap to some extent, but additional ex ante public-private risk sharing solutions may be needed. There are structural causes for the insurance protection gap, for example related to the risk perception of tail events, underestimation of potential damage and moral hazard. Including risk-based premiums as well as discounts linked to adaptation and risk reduction in insurance products (as described under impact underwriting) can support the availability and affordability of insurance, including in high-risk areas, and increase the insurance penetration rate. However, more frequent and more severe disasters may act to reduce the supply of private insurance, while simultaneously making insurance more valuable from a macroeconomic perspective. As an alternative to purely private insurance, public-private partnerships can help to ensure prompt funding for reconstruction after disasters, while also promoting adaptation and risk reduction.

Governments can play an additional role in increasing the ability of economies to recover from disasters, and the cross-border nature of catastrophe risks calls for a concerted policy response, possibly at the European level. A common EU-level approach to (ex ante) disaster risk management is lacking, and legal requirements are fragmented between hazards and



countries.¹²¹ Going forward, policymakers may consider whether knowledge-sharing at the European level could enhance risk management and modelling capabilities for natural catastrophes and foster more efficient capital allocation. Furthermore, risk pooling at the regional or European level could potentially improve insurability and affordability.

The respective roles of governments and the private sector and their interaction are further key issues to be explored in this context.

In the event of major catastrophic events, governments might be induced by public opinion to intervene and engage substantial fiscal resources to reconstruct damaged property, for example. On the other hand, engaging the liability of governments via an insurance mechanism might create potentially large contingent liabilities on the balance sheets of fiscal authorities. A layered approach, where risks are shared at different levels, based on central coordination and conditional upon the implementation of efficient and effective prevention and adaptation measures, could be considered:

- (i) Better mutualisation of risks among policyholders, i.e. between those likely to be affected by physical risks (e.g. on the coast or near rivers) and those likely to be less affected.
- (ii) Better bundling of different insurance risks: designing insurance products that cover not only damage to property but other bundle coverage for various insurance risks (e.g. flood, hail, storm and earthquake).
- (iii) Co-insurance or reinsurance mechanisms between private insurers in order to pool risks, or the transfer of risks to the capital market via securitisation (e.g. cat bonds) where risks are not correlated.
- (iv) Mechanisms whereby governments (or government owned companies) against the payment of insurance premium /surcharges on (mandatory) insurance, provide a backstop above certain thresholds (e.g. defined in terms of damage or conditions of natural catastrophic events).
- (v) Government policies to limit risk exposure: beyond insurance, governments could provide guidance on the areas (e.g. building codes and building permits) that cannot be insured because of the likelihood of extreme damage is too high.

Financing the transition

Capital markets are an important complement to bank lending and public investments in closing the investment gap in the green transition (Born et al., 2021). The climate and energy targets set out at the European level require major technological investments, with associated financing needs by 2030 estimated at around € 330 billion every year (European Commission, 2020). The redirection of financial flows towards green investments substantially mitigates physical risks in the longer term. The scaling up of green finance, and the structural changes it will bring

¹²¹ See for example European Commission (2021e) “**Closing the climate protection gap - Scoping policy and data gaps**”, and European Commission (2021f), “**Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change**”.



about in the financial system, could give renewed impetus to initiatives to build a single market for capital across Europe. At the same time, when designing public policy measures supporting transition financing, policymakers should be mindful of potential unintended consequences, such as contributing to the build-up of both "green bubbles" and greenwashing risks. In this context, the responsibility for directing and supporting transition financing first and foremost lies with governments and financial market participants, while macroprudential policy needs to remain risk-based and, at the same time, consider potential unintended consequences for transition financing.

Economies with a higher share of equity funding tend to reduce the carbon footprint more rapidly. Closing the equity and risk capital investment gap in Europe could thus not only help to reduce the risks from increased corporate financial fragility in the post-pandemic recovery, but also help the green transition (Brutscher and Hols, 2018). Equity finance – and in particular venture capital and private equity, as an essential source of funding for start-ups and high-growth companies – has a crucial role to play in the green transition, as technological innovation to decarbonise the EU's energy system has been clearly identified as a key enabler of the net zero targets (European Commission, 2020). Equity financing of innovative European firms in the field of environmental technologies has increased in recent years and continued to grow steadily during the COVID-19 period (Kraemer-Eis et al., 2021). Recent research documents the attractiveness of green patenting for venture capital investment in the medium term in Europe, which suggests strong potential for facilitating the adoption and diffusion of environmental technologies (Bellucci et al, 2021).

Measures under the European Commission's capital market union action plan and the sustainable finance agenda could help facilitate access to market funding and grow EU equity markets. It will be important to make further progress with measures under the EU capital markets union umbrella that are particularly relevant for the development of green capital markets, such as the ESAP, a Europe-wide platform that consolidates financial and sustainability-related public information about EU companies and EU investment products. Likewise, it will be crucial to enhance the comparability and standardisation of sustainable finance products, for example through the envisaged European green bond standard built on the EU taxonomy or the CSRD directive, which aims to improve the quantity, quality and availability of sustainability-related information.

4.4 Existing evidence of the effectiveness of policy options

An emerging body of literature discussing the impact of (macro)prudential measures provides initial insights that inform the selection, design and calibration of macroprudential policies addressing climate risks. Both theoretical and empirical work has already shed some light on the potential effects of some of the policy tools discussed in this report. More work by institutions and academia is underway that will further inform the ongoing discussion on macroprudential policies for climate risks.

A few papers using simulation-based methods provide some initial guidance on the effectiveness of (macro-)prudential policies. Several studies have investigated the effects of imposing a green supporting factor (GSF) or a dirty penalizing factor (DPF). Alogoskoufis et al.



(2021) jointly assess the impact of a GSF and a carbon tax. Their work suggests that a GSF has both limited ability to foster the transition and may fuel green bubbles with negative financial stability implications. They also find that a combination of carbon tax with welfare measures fosters the low-carbon transition while preventing unintended effects. Diluio et al. (2021) use a dynamic general equilibrium model with financial frictions to evaluate macroprudential capital requirements. Their analysis suggests that the introduction of fossil fuel penalising capital requirements, rather than green supporting schemes, may be a more suitable tool to mitigate output losses and stabilise the economy. Lamperti et al. (2019, 2021) find that capital requirements differentiating between green and non-green, carbon-intensive assets and countercyclical capital buffers can mitigate emissions and can increase productivity without detrimental effects on financial stability. Interestingly, they find that a policy mix of capital requirements, green public guarantees of credit and carbon risk adjustment in credit ratings yield the best results. In a micro-theoretical setting, Oehmke and Opp (2022) find that climate-related risks that affect bank stability can be optimally addressed by a combination of GSF and DPF.

The empirical literature on this topic is still very limited, due to a lack of implemented prudential climate tools. Chamberlin and Evain (2021) represents an early attempt to combine data from French banks with a model-based simulation approach to estimate the effect of a GSF and a DPF. Their work suggests that both measures would have limited impact and come with unintended side effects, and that other prudential measures would be preferable. Going forward, the introduction of prudential policies tackling climate risks will provide more opportunities to use empirical approaches to complement the conceptual and theoretical discussion.

This section features two selected studies that analyse the potential for macroprudential policy to address transition risk to the banking system. First, Alessi et al. (2022) (see Box 9) propose a framework based on a micro simulation model to discuss the usefulness of additional capital buffers for transition risks. Second, a dynamic stochastic general equilibrium (DSGE) framework proposed by Chaves et al., (2021) is used to assess whether relying on microprudential regulation alone is sufficient to account for the systemic dimension of transition risk (see Box 10). Both studies suggest that macroprudential policies may indeed be useful in safeguarding the banking system against transition risks.

Some studies have analysed the impact of initiatives designed to increase market transparency, reduce greenwashing and help drive a green transition in the market, respectively. With respect to the EU taxonomy, Alessi and Battiston (2021) estimate that currently only 1.3% of EU financial markets support taxonomy-aligned activities, a figure which is expected to increase owing to market, technological and regulatory developments.¹²² Some contributions have shown that green bonds are associated with a significant reduction in total and direct emissions of non-financial companies and may improve firms' environmental footprint when independent third parties certify bonds. A premium for green bonds may exist if investors are able to identify a clear link between the bond issued and a specific green investment project (Fatica and Panzica, 2021, Flammer, 2019, Fatica et al., 2021).

¹²² See also Chapter 4.3 on estimating transition risk in financial portfolios based on a similar methodology. In particular, the approach uses taxonomy alignment coefficients (TAC) to weight each asset in the portfolio based on the NACE sector of the investee company or borrower.



While the work summarised in this section provides some useful first insights informing the discussion on macroprudential policy measures, more work is needed to ensure a sound basis for their proper selection, design and calibration. Going forward, we expect a significant increase in the number of relevant studies emerging from academia as well as policy institutions. Moreover, the next phase of this Project Team will aim to provide more in-depth analysis with the specific objective of informing the ongoing policy discussion on these measures.

Box 9

Accounting for climate transition risk in banks' capital requirements

The framework proposed by Alessi et al. (2022) is one attempt to quantify the impact of transition risk on banks' balance sheets. On the basis of the size of banks' exposures to high carbon activities, the model estimates potential losses, and could potentially help with the calibration of relevant macro-prudential capital requirements.

Estimates of banks' transition-risk exposures are based on the methodology developed by Alessi and Battiston (2021), presented in Chapter 4.4. A micro-simulation model is then used to estimate the impact on financial stability of increased risks in the following two scenarios: i) a banking crisis triggered by non-climate-related factors, where transition risk comes on top, and ii) a fire sale of high-carbon assets, which could unfold in the short term.

In the first scenario, due to climate transition risk, losses would increase by around 20% or more in one third of EU countries, indicating rather concentrated risks. In the second scenario, an initially contained shock, putting only few banks under stress, could nevertheless trigger uncontrolled market dynamics, which would put more banks under stress, ultimately leading to significant losses for the EU banking sector. An extra capital buffer proportional to the transition risk faced by each institution would successfully protect the system, as all banks would be adequately protected, so a fire sale would not even start. An extra capital buffer of around 0.5% of RWA on average, or 3% of existing capital, would be sufficient. However, Figure A shows that banks whose transition risks are concentrated would need to set aside more capital (up to 4.5% of RWA in very extreme cases).

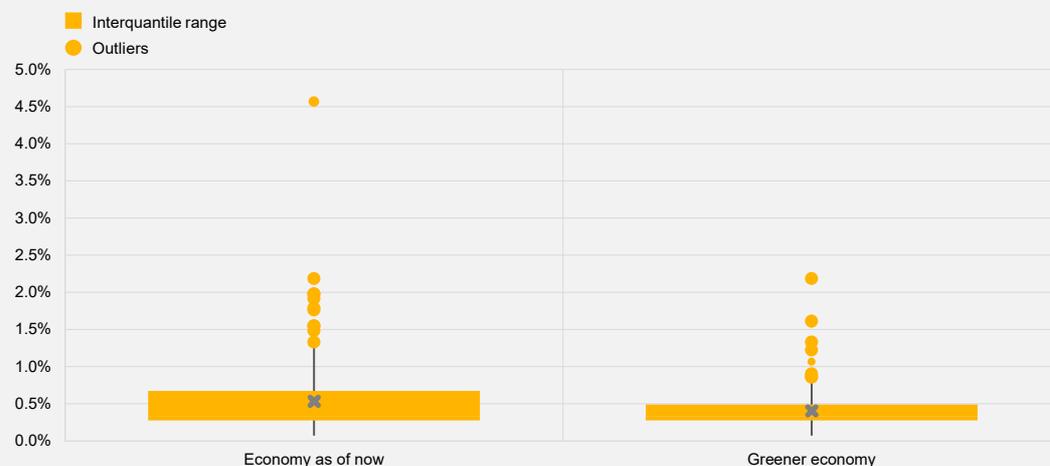
Climate-related capital buffers could be gradually phased out in a scenario where an orderly economic transition gets increasingly reflected in greener bank balance sheets. With bank counterparts carrying out fewer harmful activities, bank portfolios would automatically become greener without any major selling-off. Hence, losses due to a fire sale would reduce by a factor of ten. In this case, the additional capital requirements needed to completely offset residual transition risks for the EU banking sector would be less demanding, i.e. around 0.4% of RWA on average (or 2% of existing capital), and up to 2% of RWA for the most exposed banks. The reduction in losses would be more pronounced if countries and banks that are less green today became greener more quickly, as opposed to a situation where risks decrease on average but remain concentrated.

Overall, an institution-specific or country-specific buffer, reflecting the specific exposure to climate transition risk, would successfully protect the system for as long as necessary, while minimising overall costs by addressing risks directly where they are.



Chart A

Distribution of additional capital requirements needed to offset transition risk (as a % of RWA)



Source: Alessi et al. (2022), based on ECB Securities Holdings Statistics, Orbis BankFocus, and authors' calculations.

Box 10

A theoretical case for macroprudential policies addressing climate transition risk

Are microprudential policies sufficient to cater for transition risks? While there is consensus that transition risk can generate financial stability risks which are not fully addressed by the current regulatory framework, it is still unclear how systemic this risk is (see Baranović et al., 2021). The framework proposed by Chaves et al., (2021) is used to assess whether relying on microprudential regulation alone is sufficient to account for the systemic dimension of transition risk. In the presence of transition risk affecting individual firms as well as in the form of an aggregate demand shock, for example in the form of a shock to household consumption preferences, shifting the consumption of goods produced by (medium- and high-) polluting firms to green firms, introducing macroprudential policies in addition to microprudential regulation results in a Pareto improvement in the equilibrium allocation of exposures to transition risk.

The analysis is based on a DSGE model with heterogeneous banks and firms. Firms produce the same type of products but are characterised by different degrees of carbon emission intensity. In equilibrium, banks have heterogeneous portfolios of exposures to firms with different degree of carbon intensity. While banks take into account the transition risk of their own exposures at portfolio level, they do not account for common demand shocks. This gives rise to suboptimal portfolio allocations due to inefficient risk-taking by the banking sector with respect to transition risk.

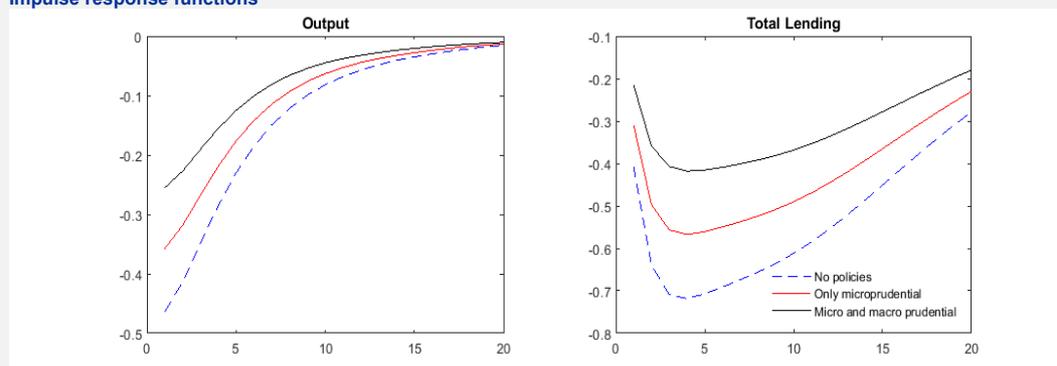
In the model, microprudential policies are implemented via capital requirements calibrated on the transition risk of the individual banks' exposures, while macroprudential policies are represented by an add-on requirement for all banks calibrated on sectoral transition risk exposure. Model-based simulations rely on an adverse transition risk shock which could lead to a decline in output of 0.45% and of lending of 0.7% (see Chart A, dashed blue line). In this case, a lifting of the microprudential



requirements could mitigate the impact on output and lending of 0.15% and 0.1% respectively (see Chart A, red line). The introduction and release of also the macroprudential measures could lead to a further mitigation of the shock impact on output and lending of 0.1% and 0.15%, respectively. Overall, introducing a macroprudential capital buffer on top of differentiated risk-weights improves the equilibrium outcome by safeguarding banks against common transition risk shocks.

Chart A

Impulse response functions



Sources: Chaves et al., (2021), based on ECB supervisory data and authors' calculations.



5 Conclusions

This report addressed pressing analytical needs in the areas of climate risk measurement, while initiating work on mapping the growing body of gathered evidence to macroprudential policy reflections. Progress was made in three areas. A first focus area was data and measurement: examining data consistency, while translating financial exposures to climate risk into risk metrics relevant to macroprudential policy. A second focus related to the deepening of the modelling of forward-looking aspects of climate risk, spanning scenario refinement, as well as more in-depth impact assessments for the entire European financial system. A third focus area was building a case for evidence-based macroprudential policy, in lockstep with international efforts to ensure systemic resilience.

As work has progressed, increasingly refined and specialised needs will structure further work on this complex topic. In recent years, this ESRB/ECB Project Team has leveraged the analytical capacity of its members to strengthen evidence-based macroprudential considerations, complementing other initiatives in the evolving debate in the public and private sector alike. The focus will in future shift to strengthening an evidence-based case for policy action in the EU, consolidating and developing what is necessary to make prudential policy recommendations. This will involve, on the one hand, a mainstreaming of analytics, while further closing some key knowledge gaps further and, on the other, developing a more concrete view of how existing evidence can be used to inform macroprudential policy in the sphere of climate and broader environmental considerations.



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