Towards macroprudential frameworks for managing climate risk

December 2023

by
ECB/ESRB Project Team
on climate risk

EUROPEAN CENTRAL BANK
EUROSYSTEM

ESRB
European Systemic Risk Board
European System of Financial Supervision

Contents

1 Executive summary

This report proposes three frameworks for relating climate risks to financial stability – addressing risk surveillance, macroprudential policy and broader risks to nature. A first framework covers financial stability risk surveillance. It takes stock of advances in measuring and modelling the impacts of climate risk, proposing a list of indicators for regular financial stability risk monitoring. A second framework details macroprudential policy options. It outlines both the features of a robust strategy as well as an initial operational design based on existing instruments, which can be scaled up as further information and more tailored policy options emerge. A third framework takes a first look at prospective financial stability impacts stemming from nature degradation, which could serve to exacerbate the financial stability impacts of climate change.

A surveillance framework

A growing list of indicators can be curated into a framework for monitoring climate risks to financial stability that is flexible enough to incorporate new information as it emerges. The surveillance framework proposed in this report and the accompanying **Chartbook** consists of several building blocks. A first surveillance block tracks the increasing salience of climate shocks, spanning both transition and physical risks. A second block focuses on exposures of entities in the European Union (EU), both financial and economic, to these climate shocks. A final block considers the intersection of climate risk and financial vulnerability, using a set of financial risk indicators. These measure not only direct exposures but also amplification through interaction between the real and financial sectors (notably the prospect of systemic aspects). The surveillance framework presented in this report can be adapted to incorporate ongoing improvements in the measurement and modelling of climate-related risk. To cater for such analytical advances, the framework is scalable and is also flexible enough to accommodate further measurement advances.

Available indicators suggest heterogeneous exposures to climate risk across EU countries, sectors and firms, with access to consistent information on adaptation measures remaining limited. Firms' carbon emissions currently vary greatly both across and within sectors. Firms also exhibit strong heterogeneity based on forward-looking information – encompassing emission reduction targets, transition investment, exposure to high-carbon assets and portfolio alignment. As transition planning continues to proliferate, it is noteworthy that figures disclosed by firms remain subject to inaccuracies, with external validation tending to result in direct emissions estimates around 7% higher. For households, even data on emissions remain scarce. Survey-based estimates of average energy costs across EU countries range from below 8% of expenditure to above 20%. While more granular datasets for households at the EU level remain elusive, available country-level evidence suggests uneven emissions across geographic areas and income groups.[1] Government exposures to climate risk importantly relate to managing the pace and scale of transition,[2] while on the physical risk side much climate-related risk stems from contingent impacts

[1] See ECB/ESRB (2022), **The macroprudential challenge of climate change**.

[2] See also Fahr et al (2023), **Climate change and sovereign risk**, ECB Financial Stability Review (May).

on expenditures and revenues resulting from climate shocks. Standard debt sustainability analyses suggest that first-order impacts of physical climate disasters could push up sovereign debt by over five percentage points of GDP for some euro area countries. Any materialisation of contingent liabilities, alongside difficult-to-quantify climate “tipping points”, could add significantly to potential sovereign risk associated with climate change.

Turning to financial intermediaries, banks will be key in managing and reducing climate-related financial stability risks, with lending disproportionately tilted toward firms and households with high climate risk exposures. With the carbon footprints of EU banks having shown little sign of decreasing in recent years, banks remain strongly exposed to carbon emissions in their lending portfolios. The share of high-emitting economic sectors in bank lending is around 75% higher than its equivalent share in economic activity, while more than 60% of banks’ interest income derived from firms operating in the most carbon-intensive sectors. Exposures to the real estate, construction, and wholesale and retail trade sectors stand out most as requiring transition risk management. A tilt in mortgage borrowing towards high-emitting households is noteworthy, as they comprise typically 60-80% of total mortgage lending in euro area countries. Beyond transition risk, the physical risk of lending portfolios is also substantial. More than 50% of total loan exposures towards firms in the mining, water supply and wholesale sectors are affected by extreme flood risk, while more than 10% of exposures towards the mining sector are affected by extreme wildfire risk.

High climate risk exposure is not distributed evenly across banks. For transition risk, exposure concentrations are high in a subset of banks. They would face substantially larger losses than their more diversified peers when confronted with a transition shock. The impact of portfolio concentration could lead to a 60% increase in expected losses on corporate lending portfolios during a disorderly transition. The lack of information on clients’ transition plans prevents a proper aggregate assessment of how these exposures are being managed. Available data indicate that the adjustment of bank portfolios has remained limited, with only slow shifts in portfolios towards activities aligned with EU environmental objectives. Concerning physical risk, potential exposures to climate hazards remain highest for water stress, wildfires and subsidence.

Climate risk exposures may give rise to financial risk through the interplay with financial vulnerabilities. Banks’ vulnerability towards combined transition and credit risk via their loan portfolios could triple in the event of a pronounced shock. At the same time, underprovisioned credit risk is highly concentrated among relatively few banks: in a disorderly transition, around a quarter of total loan portfolios might already account for some 50% of total additional losses within just a few years. Concerning physical risk, the construction, manufacturing, transport, and wholesale and retail sectors present the highest physical-to-credit risk intensity for both flood and wildfire risks. The portfolios of smaller firms, in particular, carry a relatively higher risk, given that small and medium-sized enterprises (SMEs) tend to operate more locally and are highly reliant on bank credit.

Scenario analysis can usefully complement the above surveillance metrics, providing a view on challenges ahead in case of compound shocks (involving both climate and financial disruptions). The report focuses on short-term actionable scenarios, as managing climate risks interacts with near-term economic and financial realities. Well designed scenario analyses can be useful in compounding climate risks with adverse economic and financial conditions, leveraging standard stress test exercises focusing on shorter actionable horizons for policymakers, economic sectors and financial markets alike. This scenario analysis reveals that climate-related losses in a pronounced energy transition would not be evenly spread – with electricity and gas, manufacturing, wholesale, and mining being among the most exposed sectors.

Moving from banks to financial markets, effective financing for a sustainable transition remains limited. While holdings of sustainable debt securities have been steadily growing in recent years, they still account for a relatively limited share of the wider financial market, with sustainable markets comprising only 10% of the euro area investment fund sector and 3% of outstanding bonds. Any pricing advantage offered by green instruments (known as the "greenium") seems to be dissipating, possibly reflecting a shifting supply-demand balance as green markets mature. And, regarding the securities holdings of non-bank financial intermediaries, considerable portfolio similarity across firms may imply scope for fire sale externalities when reacting to pricing shocks, with scope for correlated exit of financial positions as climate concerns become more salient.

Four systemic mechanisms may serve to amplify losses from climate change, including those which might otherwise appear manageable. Many estimates of losses resulting from first-order impacts of climate change appear manageable at face value, particularly over a long horizon. However, several systemic risk channels could bring forward seemingly distant losses or amplify seemingly concentrated losses. The prospect of these sources of amplification, not reflected in past data, would not be reliably captured by traditional back-testing, no matter how rigorous. A first source of systemic amplification is climate shocks – even seemingly localised hazards related to heat and water stress tend to be self and mutually-reinforcing and could lead to abrupt financial market repricing. A second source of systemic amplification is economic – global supply chains could imply shock propagation across borders. This is particularly relevant for the euro area as a very open economy, in which international exposures could magnify domestic losses due to floods multiple times, depending on the potential for trade reallocation. A third channel of systemic amplification relates to traditional financial externalities in the event of rapid changes in financial sentiment – noting interactions across financial participants could amplify shocks as climate risks become more salient. Traditional counterparty risk might be a particularly strong source of risk propagation through the financial system, through credit, market and liquidity linkages across financial firms. A final source of prospective systemic amplification, and a particularly difficult one to assess, is risk transfer – sovereigns might be tempted to step in to cover underinsured climate losses. The insurance protection gap across euro area countries is noteworthy, with only 25% of average climate losses currently insured (and up to 95% of climate losses remaining uninsured in some countries). This significant protection gap is likely to worsen if climate shocks continue to become more potent and leaves both financial institutions and governments heavily exposed to climate risk.

A macroprudential policy framework

A growing body of evidence on the risks to financial stability from climate change is providing the foundation for detailing a macroprudential strategy for the EU. Over the last years, several advances in measuring and modelling climate-related risks to financial stability have clarified where and how financial risks may emerge. These advances provide the foundation for an evidence-based macroprudential strategy.

When devising prudential policies for climate risk, a holistic approach is needed – encompassing both microprudential and macroprudential perspectives. Microprudential authorities have been actively taking necessary steps to increase the resilience of financial institutions to climate risks. A macroprudential counterpart can provide a powerful complement, broadening the scope to common exposures, propagation within the financial sector and feedback loops between the real economy and the financial sector. It can also support the management of unevenly distributed risks at the euro area country and region level, with potential for spillovers and contagion. A holistic approach across both microprudential and macroprudential aspects could aim to bolster resilience and capabilities of individual institutions with targeted supervisory action at the microprudential level, while macroprudential policy addresses systemic risk by reducing risk build-up, increasing resilience to the amplifications of climate risks and focusing on attenuating the potential for and materialisation of tail events. While there is in principle a separate basis for microprudential and macroprudential aims, in practice the deployment of prudential measures will clearly require a close dialogue between microprudential and macroprudential authorities in order to ensure an effective and efficient policy mix. Moreover, a financial risk focus is key to prudential policy effectiveness in any form – as public policies such as carbon pricing remain the appropriate policy for directly addressing climate change itself.

As the understanding of climate-related risk evolves, a gradual, targeted and scalable macroprudential approach appears most appropriate. Broadly speaking, policy responses need to weigh the cost of early action based on imperfect information, against the risk of acting too late. Measures could be applied progressively, over time – as analytical advances manage to resolve remaining uncertainties about the timing and nature of transition and physical climate risks – to address either absolute system risks or relative risks. Targeted measures geared towards aligning incentives with macroprudential goals rather than increasing requirements across the board might be considered a useful first step. Such a gradual approach would also ensure that risks were being addressed while limiting any negative side effects on the provision of the necessary funding for transitioning firms.

A general macroprudential strategy in the European Union would pay significant attention to banks, given their key financing role in the region. Measures directed at banks can be complemented by direct measures to contain risk for borrowers. For banks, macroprudential policy can be effective in addressing lender vulnerability linked to both an absolute and a relative increase in risks. Capital-based measures to contain systemic risk (such as dedicated capital buffers) could build resilience against potential systemic losses that are unexpected and unaccounted for. Granular definitions of risk exposures accounting for forward-looking transition trajectories could enhance the efficiency of such buffers and limit possible side effects on transition and adaptation financing. To reduce the systemic risk from climate change, a more targeted application of macroprudential tools could address concentrated vulnerabilities – though this would require close cooperation with microprudential counterparts during deployment. Such measures could include concentration thresholds triggering prudential action (enhanced supervisory monitoring, concentration charges or buffers triggered once a certain threshold is reached), and tools to address vulnerabilities directly at the level of borrowers – be it firms or households – including borrower-based measures (BBMs).

Operationalising such a common macroprudential strategy across EU countries and sectors is already possible. In the EU, the systemic risk buffer (SyRB) is already available for use and is flexible enough to fit a range of design options, depending on the scope or choice of exposures, buffer rate structure, activation and calibration approaches, which can be tailored to the relevant risks and operational constraints. Targeted amendments, while not strictly necessary, could be beneficial for mechanisms such as the sectoral systemic risk buffer, which would become more effective and efficient if we had a harmonised definition of the appropriate subsets of sectoral exposures. However, concrete activation and calibration options are already within reach. As data gaps are gradually closed, BBMs may also usefully complement capital-based measures in addressing borrower exposure to transition and/or physical risks that may adversely affect their solvency. These measures would take time to have an impact, as they apply only to new loans. Yet the uncertainty and potential costs of identifying physical and transition risks suggest that banks might have little incentive to internalise these risks, and thus BBMs could be a useful and effective tool in anchoring credit standards.

At the same time, policy needs to be encompassing enough to tackle a growing role for non-bank financial intermediation in financial stability. For non-banks, addressing market failures from informational asymmetry or moral hazard through enhanced transparency provides an immediate way to limit the build-up of risks as a nascent toolkit takes shape. Policies to enhance levels of disclosure and address potential greenwashing risks are an integral part of the macroprudential toolkit for addressing climate risks, as they are instrumental in reducing asset mispricing and repricing risks by ensuring market transparency. Addressing the existing – and growing – insurance protection gap is key to increasing our overall resilience to physical risks, while minimising the risk of systemic spillovers of uncovered losses to the broader financial system. Building on existing frameworks of private insurance and public sector intervention, a ladder approach to policy responses may be considered – whereby risks could be more efficiently insured ex ante through enhanced private reinsurance/reinsurance, complemented by risk transfer to the broader capital markets. To address residual limits to insurability, public sector solutions adapted to national circumstances may be needed, including public-private partnerships (PPPs) and ex ante public backstops – which could be reinforced by an EU-wide component. Harmonising the insurance penetration rate could lead to considerable benefits, with simulations showing up to an 80% reduction in losses for countries where the actual penetration rate is low. These benefits of adaptation in affected areas will ultimately need to be balanced alongside managed retreat, with moral hazard where risks might become too large to insure. Lastly, tools used within the banking sector, such as the SyRB or BBMs, may also be useful in building general resilience against risks in the non-banking sector.

All in all, a common EU approach is essential to avoid fragmentation and appropriately tackle a common risk which is global in nature. Prudential policies will need to tackle heterogeneity to improve the overall efficiency of policy response against systemic climate risks. Close coordination of policy responses across countries and sectors, especially within the EU, will be essential if we are to efficiently address systemic climate risks, by limiting the risk spillovers, uncertainty and distortions that might result from a more fragmented approach.

A framework for exploring broader risks arising from nature degradation

The third and final framework discussed in this report examines broader risks stemming from nature degradation, as they are closely related to climate change. On the one hand, climate change is a driver of nature degradation. On the other hand, nature degradation could be a driver of climate change, while nature restoration could facilitate climate change mitigation and adaptation.

Given these links between climate and nature risks, we explore conceptual aspects of nature-related risks to financial stability, alongside estimates of the dependence of the EU financial system on nature. This report provides a conceptual overview of nature-related risks by laying out concepts, EU case studies and various initiatives among EU institutions. Much like climate risk, nature risks have both a physical aspect (resulting from the degradation of nature) and a transition aspect (resulting from measures to protect, restore or reduce physical impacts). Several economic sectors could be directly exposed to nature degradation, including agriculture, mining, and infrastructure – while retail and services sectors could be impacted indirectly. We outline several exposure analyses for EU countries, as part of the initial steps towards a forward-looking risk assessment to tackle the problem of financial stability risk resulting from nature degradation.

Initial findings suggest that nature degradation has the potential to cause material impacts, both chronic and acute. Chronic physical risks would likely accumulate in the agricultural and related sectors, while acute physical risks relate mainly to freshwater. Notably, water-dependent sectors in the EU, such as manufacturing and agriculture, generated 26% of the EU's annual gross value added in 2015. The materialisation of these nature risks could have dire consequences, as European financial institutions are heavily exposed to sectors that are highly dependent on nature. Indeed, 75% of corporate loans among euro area banks and 31% of investments in corporate bonds and equity among European Economic Area (EEA) insurers are to economic sectors that are estimated to have a high dependency on at least one ecosystem service. These exposures could materialise in the form of credit risk, market risk or operational risk, including litigation risk. Going forward, further work will be needed to move from exposure analyses to nature-related scenarios that would serve to better estimate potential financial losses.

Closing a chapter

This report marks the end of the work of this ESRB/Eurosystem Climate Risk Project Team. Over the years, the team has sought to provide a quantitative view of risks for policymakers and the general public alike, leveraging ESRB/Eurosystem proprietary data and expertise to inform an often heated debate. While several gaps undoubtedly remain, the frameworks presented in this report can provide a structured foundation for integrating macroprudential perspectives on climate into ongoing risk surveillance and prudential policy discussions in the EU.

2 Introduction

This report presents three frameworks for understanding and contextualising climate-related risks to financial stability. The first framework aims to mainstream climate-related risks into standard financial stability assessments for the EU. The framework curates a growing body of empirical evidence into a framework suitable for regular monitoring, which can be completed as measurement and modelling gaps are further closed.[3] This report outlines comparable sets of data sources for monitoring the trend in climate-related systemic risk across the EU financial system, and describes methods to assess the resilience of the financial sector to climate-related risks. The second framework outlines a strategy for tackling macroprudential policy risks and explains how it might be operationalised based on the existing macroprudential toolkit – providing a set of macroprudential options for climate risks. The third framework is more conceptual and could be used to evaluate broader nature-related risks for the EU. As measurement and modelling of climate-related risks has matured, broader risks to nature can help to understand any symbiotic relations with climate-related risk, noting a likely interplay both on the physical and transition risk side.

This report is organised as follows: Section 2 outlines a framework for monitoring climate risks to financial stability, contextualising recent strides into a chartbook suitable for regular monitoring,[4] while also describing the progress made in modelling the forward-looking attributes of climate change. Section 3 recalls the rationale for macroprudential policy, and presents how a growing body of evidence can underpin a macroprudential response to the associated risk. Meanwhile, Section 4 introduces nature-related risks and Section 5 contains our conclusion.

[3] This evidence notably includes previous reports of this ECB/ESRB Project Team on climate risk monitoring, including ***The macroprudential challenge of climate risk***, July 2022; ***Climate-related risk and financial stability***, July 2021; and ***Positively green: Measuring climate change risks to financial stability***, June 2020.

[4] See ECB/ESRB Project Team on climate risk monitoring **Chartbook**, alongside **Annex.**

3 Surveillance framework

The financial stability impacts of climate-related risks on both the real economy and the financial system depend on the interplay of exposures and financial vulnerability. A financial stability surveillance framework requires us to measure not only financial sector exposures to transition and physical risks, but also their transmission and potential amplification within the real economy and the financial system ultimately leading to systemic risk. This section outlines a surveillance framework and its constituent metrics for monitoring climate-related risks to the financial system and tracking progress towards a net-zero economy.

The proposed framework covers climate risk, economic sectors, and the financial system with various financial instruments (loans, debt securities and equities). The first section encapsulates climatic indicators[5], ranging from temperature developments to physical hazards such as floods, droughts and water and heat stress (Figure 1). These indicators are essentially the foundational layer, providing a snapshot of the current and projected states of climate factors that could pose risks to economic and financial stability. Global, euro area and country-specific temperature patterns are shown and monitored with respect to theoretical warming thresholds associated with global tipping points. High-resolution data from different sources are employed to construct maps and visualisations in order to show the historical trend as well as forward-looking projections of water stress, river flooding, sea level rise, wildfires and droughts.

The second section delves into the exposures to climate-related factors of the real economy and, indirectly, the financial system. It covers greenhouse gas (GHG) emissions from households and firms, as well as their exposure to flood and other hazards. Monitoring these exposures across individual agents, sectors and regions offers valuable insights into the vulnerabilities present with the financial system and allows us to adopt more targeted risk management strategies. Over time, it also provides useful information on potential deviations from net zero strategies.

The third section moves from exposure mapping to climate-related risks and vulnerabilities in the financial system, incorporating also green and sustainable financing, and provides information on the vulnerabilities and systemic risk present within the financial system. It includes new forward-looking metrics, a novel analysis on localised risk metrics to assess vulnerabilities among banks, and insights into the effect of climate risks on public finances and insurance premiums. Moreover, the section explores how climate change can generate systemic risk, whereby direct climate-related events trigger cascading feedbacks through the economy and the financial system, with the aim of identifying potential amplification effects that could turn localised risks into systemic threats for the economic and financial system.

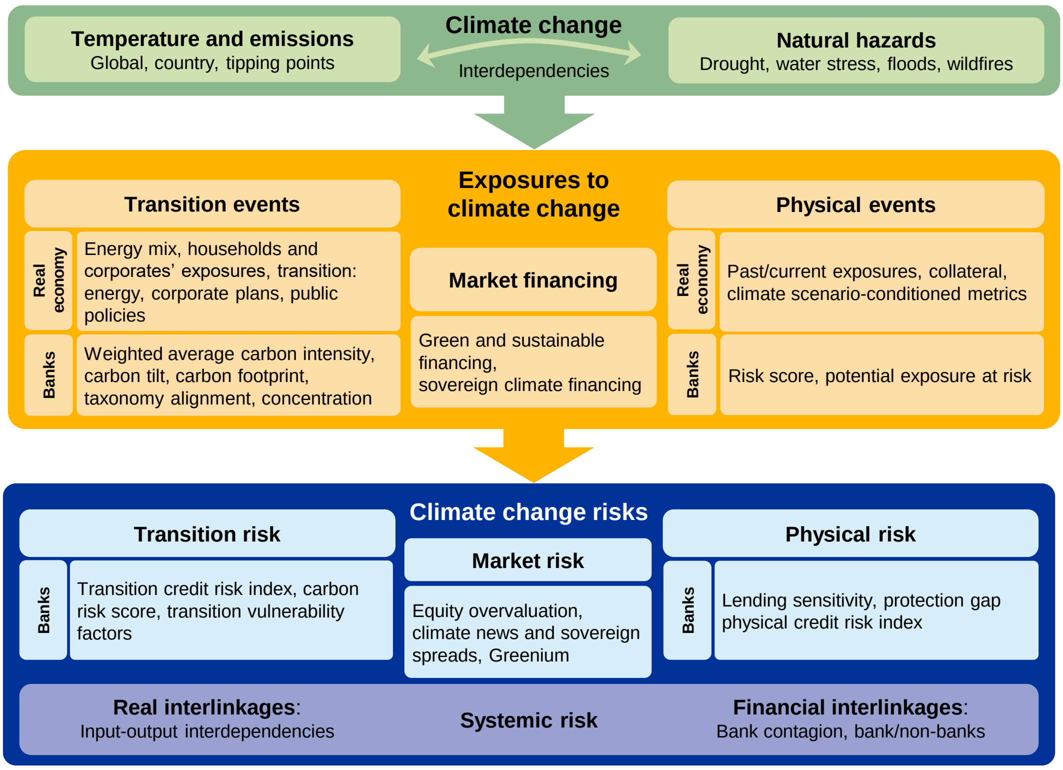
This framework is scalable and can be updated as existing challenges and gaps are tackled and overcome. Data availability and discrepancies in reporting standards are among the key issues that need to be addressed in order to make surveillance more effective. The framework presented in this section complements existing initiatives, such as the European Central Bank

[5] The first section of the monitoring framework is not discussed in this report, which is focused on financial indicators. Climate indicators can be found in the ECB/ESRB Project Team **Chartbook** accompanying this report.

(ECB) climate change-related indicators on sustainable finance, carbon emissions, and physical risk and those of other international bodies like the International Monetary Fund (IMF), the Organisation for Economic Co-operation and Development (OECD) and the Financial Stability Board (FSB).[6] These collective initiatives aim to promote best practices for climate-related risk assessments and foster international cooperation on climate change and sustainability issues.

Figure 1

Surveillance framework for climate-related financial stability risks



Source: ECB/ESRB Project Team.

To ensure that the surveillance framework is complete, thresholds must be defined for a set of indicators to undergo regular monitoring. Benchmarks play a key role when it comes to risk assessment as they can be used to flag potential risks and trigger alerts. Considering the forward-looking nature of climate-related risks, past developments might offer limited utility in setting such thresholds. Consequently, certain indicators may feature thresholds based on historical percentiles, reference values predicated on future scenarios, such as a level to be attained under

6 The IMF has developed a **Climate Change Indicators Dashboard**; the OECD provides a dashboard within the framework of its **International Programme for Action on Climate**: while for the FSB a monitoring framework is part its **Roadmap for Addressing Financial Risks from Climate Change**.

Representative Concentration Pathway (RCP) 4.5 by 2030,[7] or benchmarks based on stress test scenarios.

These indicators and the benchmarks against which they are assessed also serve as a barometer of progress, highlighting where interventions may be necessary and guiding the course of policy responses. Thus, the holistic approach to understanding and monitoring climate-related risks not only underscores the severity and multidimensional nature of these risks but also enables the development of targeted and effective mitigation strategies.

This report expands upon the existing set of indicators introduced in previous reports, aimed at monitoring exposures, vulnerabilities and risks. Table 1 below provides an overview of all the new indicators to have been collected and developed since the last ECB/ESRB Project Team publication (ECB/ESRB 2022). The following sections will elaborate on how these metrics, along with the surveillance framework, can be effective in assessing climate risk. Annex 1.1 provides additional details and insights on the technical methodology. Climate change indicators that serve as introductory background information for climate risk surveillance are be discussed in this report. The supplementary chartbook to accompany this report provides a comprehensive analysis of climate change metrics.

This chapter is organised as follows. Section 2.2 describes new exposure metrics for the real economy as well as financial institutions, while Section 2.3 moves beyond exposure metrics to present novel risk and vulnerability metrics for banks, the public-private insurance nexus, financial markets and systemic risk.

7 A **Representative Concentration Pathway** (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC. Four pathways are generally used (RCP2.6, RCP4.5, RCP6, and RCP8.5), and the RCP 4.5 is described by the Intergovernmental Panel on Climate Change (IPCC) as an “intermediate scenario”.

Table 1
Overview of climate indicators

Framework		Indicator	Description and key insights	
Climate change	Temperature check	▶ Global temperatures and CO_2 emissions	Historical and projected global temperature anomaly and global CO_2 emissions	Chartbook
		▶ European near-surface air temperature	Projected 2100 near-surface air temperature for EU countries, and broken down by scenario	
		▶ Global sea temperature and water level	Global sea-surface temperature anomaly and sea water level anomaly	
		▶ Antarctic and Arctic ice extent anomaly	Ice extent anomaly for the Antartic and Arctic regions	
		▶ Climate tipping points	Literature-based estimates for temperature thresholds related to Global Core and Regional Impact tipping elements	
	Natural hazards	▶ Water stress	Projected level of water stress, by country and by scenario	
		▶ River flooding	Projected percentage of flooded areas and projected change in flood intensity, by country and by scenario	
		▶ Wildfires	Projected fire weather index, by country and by scenario	
		▶ Droughts	Average projected change in number of Consecutive Dry Days (CDD) compared to 2005	
Exposures to climate change	Transition events	▶ Households emissions	Energy expenditure, estimated CO_2 emissions and estimates of household exposure and resilience	Surveillance framework + Chartbook
		▶ Non-financial corporations	Deep-dive on emissions reporting biases	
		▶ Sovereigns	Debt sustainability assessment following materialisation of climate-related shocks	
		▶ Exposures to transition risk	Exposure of the financial sector to high-emitting firms via loans and debt securities	
		▶ Carbon-financing tilt	Euro area banks' lending towards emission-intensive sectors	
		▶ Taxonomy alignment	Estimates the level of alignment of financial portfolios to the EU taxonomy for sustainable activities	
		▶ Concentrated emission exposures	Carbon-related concentration risk	
	Physical events	▶ River floods	Assesses exposure to river floods under different climate scenarios and flood return periods	
Climate change risk	Transition risk	▶ Forward-looking metrics - Transition risk	Banks' vulnerability towards transition risk and its concentration within the financial system	
		▶ Forward-looking metrics - Physical risk	Banks' vulnerability towards physical risk and its overlap with sectors' exposures towards physical risks	
	Physical risk	▶ Localised climate risk	Deep-dive on small business lending and pilot study for German regional banks	
		▶ Insurance protection gap	Insurance coverage (penetration) and premiums for flood-related risk	
	Monitoring markets	▶ Green and sustainable financing	Assets under management of euro area ESG funds and outstanding amount of green and sustainable loans	
		▶ Green sovereign bonds	Amount outstanding of euro area green sovereign bonds by country and use of corresponding proceeds	
		▶ Green bonds greenium	Greenium of euro area corporate and sovereign bonds	
		▶ Climate news and sovereign spreads	Yields of conventional and green sovereign bonds	
	Systemic risk assessment	▶ Overlapping portfolio risk	Country-hazard related portfolio similarity across financial sectors	
		▶ Physical risk amplification via trade	Cross-border transmission of physical risks via input-output interconnections	

Source: ECB/ESRB Project Team.
Notes: Chartbook indicators are those presented in the accompanying Chartbook. Surveillance framework indicators are presented in this chapter and in Annex 1.

3.1 Exposure metrics

Climate-related exposure metrics for the real economy capture the extent to which households and firms may face transition and physical risks through their use of fossil fuels, their emissions of greenhouse gases or their exposures to national hazards. Different data types need to be combined, including granular firm-level disclosures, household surveys and physical hazards across European regions, which can be monitored over time to help establish benchmarks and turning-points in exposure assessments. Overall, the base data can be further improved and strengthened to include more complete company disclosures and ensure higher standardised coverage to fill the gaps in assessments. This section starts by looking into the real economy's exposures to climate change that have been developed since the previous ECB/ESRB report (2022), and goes on to present new metrics for measuring levels of exposure among financial institutions.

3.1.1 Real economy

3.1.1.1 Households

The transition risk indicators for the European household sector cover household energy expenditure and intensity, and bank exposure to high emission borrowers. Assessing transition risk in household lending is impeded by significant gaps in regulatory data, including missing household energy variables and uncertainty regarding future climate policy, mitigation and adaptation. The results provided here supplement two existing EU surveys – Statistics on Income and Living Conditions (EU-SILC by Eurostat) and the Household Finance and Consumption Survey (HFCS by the ECB) – by providing statistical estimates of household energy and emissions using modelling results taken from the Household Budget Survey (HBS by Eurostat).[8]

Cross country and within-country heterogeneity in energy consumption represent possible sources of transition risk for banks. Previous analysis shows significant within-country heterogeneity in household energy and emissions, driven by structural (building size and type), technological (energy efficiency), locational (transport distances) and behavioural (occupant types and numbers) characteristics (ECB/ESRB, 2022). Meanwhile, cross-country heterogeneity in European average household energy consumption and emissions is driven by differences in national climatic conditions, energy mix, the built environment (houses/apartments and insulation standards) and also differences in usage patterns, preferences, household income, and the unit price of energy. Such cross-country heterogeneity is clearly evident in household expenditure data (HBS 2015), with median annual energy expenditures below €1,000 in Latvia, Lithuania and Estonia but above €3,000 in the Netherlands, Ireland and Luxemburg (Chart 1, panel a).[9]

[8] The method creates new energy and emissions estimates for all households in both the HFCS and EU-SILC datasets using results from econometric models that rely on HBS data (the latter being the only dataset in which household energy expenditures are recorded). While carbon emissions are not available in the HBS, they are estimated by combining individual energy expenditure levels and emission factors for each HBS fuel. The HFCS and EU-SILC were chosen due to the availability of variables which are aligned with the financial sector, namely outstanding balance on mortgage and mortgage payments, respectively. Furthermore, the HFCS and EU-SILC data are considerably more recent (2018 and 2021) than the HBS (2015/2016).

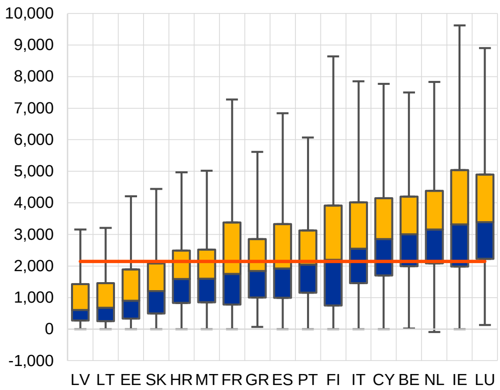
[9] This analysis excludes solid fuels due to lack of data on fuel type (coal or wood, for example).

Chart 1

Reported energy expenditure and estimated emissions across EU countries

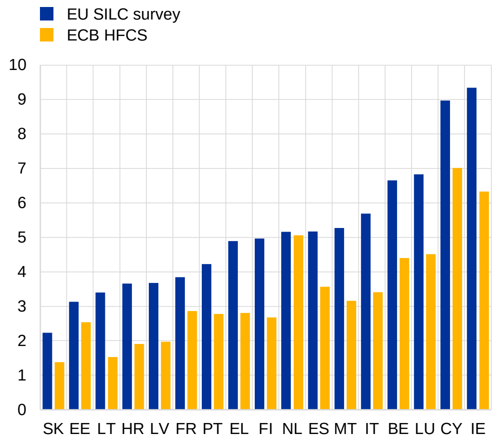
a) Mean annual household energy expenditure by country

(y-axis: €)



b) Estimated mean annual household emissions by country

(y-axis: tonnes per household)



Source: Own calculations using the Household Budget Survey Data 2015 (Eurostat), Statistics on Income and Living Conditions (Eurostat) and the Household Finance and Consumption Survey (ECB).
*Notes: Energy expenditure is calculated using HBS fuel expenditures for electricity, gas and liquid fuels (heat and transport). Solid fuels are not considered due to missing data on type (coal, wood, etc.). HBS energy expenditures are converted into emissions using national energy price data (Eurostat and European Commission) and emission factors (Sustainable Energy Authority of Ireland and European Environmental Agency). Energy and emission estimates in HFCS and EU-SILC are based on regression model coefficients from HBS data. The set of covariates are the same for every country except NL, MT, CY and HR, due to data unavailability. The boxplot displays (from top to bottom for each country) the upper adjacent value (75th percentile plus 1.5 * interquartile range), 75th percentile, 50th percentile (median), 25th percentile and the lower adjacent value (25th percentile less 1.5 * interquartile range).*

Cross-country differences in energy consumption, household energy mix and the CO2 intensity of electricity lead to significant differences in household CO2 emissions. Results from statistical models using HBS 2015 data are employed to create new estimates of energy expenditure and emissions for each household in the EU-SILC (2018) and HFCS (2021) surveys. In EU-SILC, mean emissions range from 2.2 tonnes for Slovakian households to up to 9.3 tonnes for households in Ireland (Chart 1, panel b). A comparison with HFCS estimates reveals differences in country rankings which are likely down to the differing samples, survey timing and question formats, and statistical model specifications (due to variable availability) used to arrive at the estimates in each survey.

Beyond the direct exposure measures, the datasets allow for the computation of energy-to-income ratios as a measure of household resilience to partly explain a household's capacity to absorb energy price shocks.[10] Based on EU-SILC estimates, energy-to-income ratios differ considerably across countries, ranging from below 6% in countries such as Luxembourg, Malta and Finland, to above 11% in Portugal, Croatia and Greece (Chart 2, panel a). Note the significant changes in country ranking between the metrics on resilience (Chart 2, panel a) and exposure

[10] For the HFCS, energy-to-expenditure (total household expenditure) is employed due to missing income variables.

(Chart 2, panel b), which highlight the importance of accounting for both a household's energy/emission exposure and its resources (income) when considering its capacity to absorb energy price shocks.

Beyond household variables, indicators that relate climate to debt can inform about household-related climate risks for the banking sector. For most countries in our sample, mortgage borrowing (measured on the basis of outstanding balances reported by households in the HFCS) is concentrated among households with higher emissions (Chart 2, right panel).[11] There is also considerable cross-country variation in this estimate of banking exposure, with six countries below 60% and eight above 70%.

Chart 2

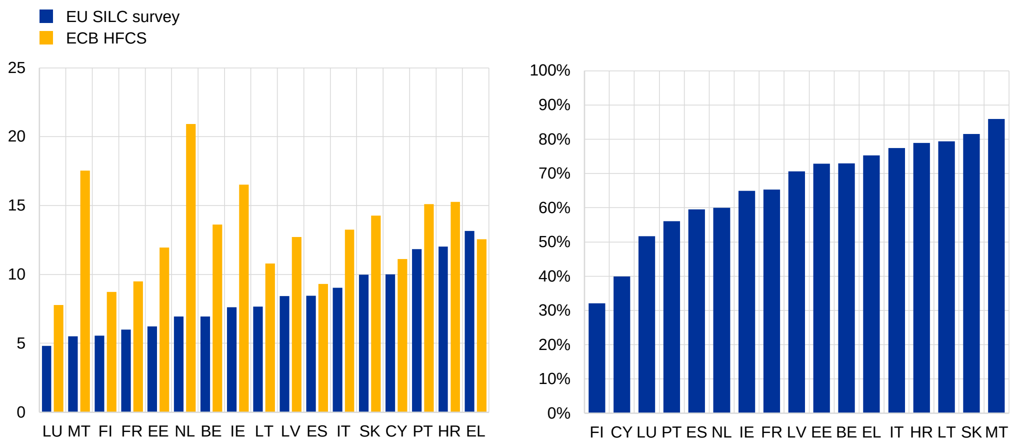
Estimates of household exposure and resilience

a) Average energy-to-income (EU-SILC) and average energy-to-expenditure (HFCS), by country

(y-axis: percentages)

b) Share of sample mortgage outstanding balance among high emitting households (HFCS only)

(y-axis: percentages)



Sources: Own calculations using the Household Budget Survey Data 2015 (Eurostat), Statistics on Income and Living Conditions (Eurostat) and the Household Finance and Consumption Survey (ECB).
Notes: Energy expenditure is calculated using HBS fuel expenditures for electricity, gas and liquid fuels (heat and transport). Solid fuels are not considered due to missing data on type (coal, wood, etc.). HBS energy expenditures are converted into emissions using national energy price data (Eurostat and European Commission) and emission factors (Sustainable Energy Authority of Ireland and European Environmental Agency). Energy and emission estimates in HFCS and EU-SILC are based on regression model coefficients using HBS data. The set of covariates are the same for every country except NL, MT, CY and HR, due to data unavailability. High emission households (panel b) are defined based on the top quartile (within each country) of the emission distribution in the HBS 2015.

These findings suggest highly significant heterogeneity in household energy consumption and emissions across European countries. The results imply that the direct costs (and benefits) of the transition would be equally heterogeneous for mortgaged households across the region, as would any indirect changes in credit risk within the banking sector. It is also clear that the energy/emission-intensity of households does not always determine vulnerability, as a household's

[11] High emission households are defined based on the top quartile (within each country) of the emission distribution in the HBS (2015).

capacity to absorb an energy price shock also depends on income, and many countries show a high vulnerability despite their low energy use and emissions. This analysis serves to highlight such differences, albeit with the caveat that the results are based on statistical estimates using an incomplete list of household energy variables – differences in rankings across these surveys (HFCS versus EU-SILC) demonstrate this caveat and there is therefore a clear need to amend regulatory data to account and prepare for transition risks in the coming years. We would also note that our assessment of exposure and risk is narrow, and that climate impacts could also come through non-energy price changes (of carbon-intensive goods and services), wages (from carbon-intensive sectors), and the slow decarbonisation of national energy supply (electricity).

3.1.1.2 Non-financial corporations

While previous reports introduced indicators to measure exposures to climate risk among non-financial corporations, this report sheds new light on the quality of the emissions reported and the availability of forward-looking data. ECB/ESRB (2022) introduced the gap between free allowances and GHG emissions as a firm-specific metric of exposure to potential changes in carbon prices. However, such metrics rely on the quality of firms' emissions data and are ideally forward-looking. With this in mind, this section analyses both the effect of assurance on firm-reported GHG emissions data as well as the availability of disclosures of forward-looking climate metrics.

Third-party assurance of reported emissions may improve the quality of corporate GHG emissions, which still suffer from substantial quality issues despite ongoing efforts to improve reporting.[12] While such third-party assurance can be effective in making carbon disclosure more comprehensive, measured by the extent of firm responses to climate-related questionnaires (Dutta and Dutta, 2021; Luo et al., 2023), the effect on GHG emissions data is unclear. To fill the gap, Papadopoulos (2023) examines econometrically the causal effect of external assurance on European firm-reported emissions data. The analysis covers nearly all companies that publicly report emissions data, mostly large, listed companies, and reveals that companies which do not externally assure their carbon disclosures very likely under-report their emissions, in some cases deliberately.

The analysis shows that third-party assurance might result in higher corporate emissions. Scope 1 emissions are on average about 7% higher when all firms externally assure their emissions, compared with no such external assurance, and this figure climbs to above 10% for the upper end of the 95% confidence interval. The impact of external assurance for location-based Scope 2 emissions is less pronounced, with such emissions being 2.4% higher in the presence of external assurance, and 4% higher for the upper end of the 95% interval.[13] The results may have important implications for firms and the financial system, as companies may have a false sense of their emissions and investors would underestimate their exposure to transition risk. With the introduction of mandatory assurance requirements, as required under the Corporate Sustainability

[12] See ECB/ESRB (2022); Papadopoulos (2022); and ECB (2023a).

[13] Robustness checks using different estimation methods make the main findings more reliable and demonstrate that they are not dependent on particular modelling assumptions.

Reporting Directive (CSRD)[14], some companies might face reputational risks and revaluations, while investors might rethink and adjust their exposures to such companies.

Beyond reporting current emissions, the disclosure of forward-looking climate metrics would allow us to assess the preparedness of the economy and the financial system for climate change. Forward-looking climate metrics using data from scenarios relate the impact of climate scenarios to common exposure metrics. From a financial stability perspective, forward-looking transition risk metrics are important for investors, lenders and insurers in assessing climate-related risks and opportunities and taking preventive action early on. They also allow us to assess how aligned businesses are with international climate objectives on the path to becoming net zero.

Recent data indicate that only a limited number of large firms disclose forward-looking transition metrics (Table 2). Forward-looking information helps to identify risks early on, possibly leading to preventive actions and thus increasing economic and financial stability. A lack of disclosure poses challenges for stakeholders looking to assess and compare commitments among firms to reducing their carbon footprints. The following list describes some useful disclosures for forward-looking metrics, along with some of the most important transition metrics and potential caveats:

- **GHG reduction targets** are central to providing a clear roadmap for businesses and investors to align their strategies with a low-carbon future and can help to anticipate gaps between national climate strategies and the real economy's preparedness to achieve them. Challenges in data comparability arise due to differences in monitoring capabilities, reporting standards and assurance processes. In addition, firms may choose to include different categories within, say, their Scope 3 emissions, or they may use different target types (i.e. absolute or intensity targets) or different reference base and target years, all of which can lead to inconsistent data.

- **Transition investment** indicates a firm's readiness for the low-carbon transition by quantifying its current investment in green technologies. The comparability may be limited due to varying definitions of what qualifies as a "transition" activity, leading to a lack of uniformity in the data reported. The absence of standardised disclosure frameworks can also result in inconsistencies in the way investments are categorised and reported.

- **Exposure to high-carbon assets** shows the proportion of a firm's assets that are tied to carbon-intensive industries, such as coal, oil and gas-related industries, indicating potential asset stranding and subsequently financial losses for investors and institutions.

- **Portfolio alignment** refers to the process of ensuring that an investment portfolio is consistent with climate change goals. Firms might employ diverse climate models and related metrics, such as implied temperature rise, leading to inconsistencies in the data they disclose. Moreover, the quality of the underlying data, its sources, and the robustness of the

[14] The Corporate Sustainability Reporting Directive (CSRD) (Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting; PE/35/2022/REV/1, OJ L 322, 16.12.2022, p. 15–80) entered into force in January 2023 and calls for updated social and environmental information, including mandatory disclosures of companies' direct and indirect emissions.

methodologies used can also vary, adding further complexity to assessments and comparisons.

Table 2

Number of EU firms currently disclosing climate risk metrics

Category	Metric	ISS ESG (2022)	Bloomberg (2022)	Refinitiv (2023)	Urgentem (2023)
Exposure	GHG Reduction Target	2367	668	425	595
	Absolute GHG Reduction Target up to 2030		357	46	368
	GHG Intensity Reduction Target up to 2030		232	22	236
	Absolute GHG Reduction Target up to 2050		85	65	312
	GHG Intensity Reduction Target up to 2050		20		167
	Net Zero Target		663		170
	Portfolio Alignment	TBD	TBD	TBD	TBD
Financial Risk	Stranded Assets		0		
	Transition Investment	775	605		

Sources: International Shareholder Services (ISS) ESG, Bloomberg, Refinitiv and Urgentem.
Notes: ISS ESG, Bloomberg, Urgentem: data from 2022 were used. Transition Investment defined as EU Taxonomy-aligned. Empty cells indicate data are not available.

This diversity in reporting practices underscores the need for a harmonised framework, not only for what outputs are reported but also for the methods and data inputs used.[15] This would help ensure that emission targets, transition investments, exposure to high-carbon assets and portfolio alignment metrics are both transparent and comparable, thus facilitating decision-making for investors and other stakeholders. With the implementation of the CSRD, large companies and listed companies[16] will have to disclose climate metrics in accordance with the European Sustainability Reporting Standards (ESRS), which include forward-looking transition risk metrics such as emission reduction targets and transition investments. The CSRD prescribes the disclosure of transition plans, while the obligation to draw up such plans is imposed by the Corporate Sustainability Due Diligence Directive (CSDDD), which is currently on the drawing board. However, given that the CSDDD and the CSRD differ in terms of scope (with the scope of the CSDDD being narrower than that of the CSRD), some companies within the scope of the CSRD may not have transition plans to disclose. Meanwhile, companies that will in the future fall within the scope of the CSDDD will need to adopt a plan to ensure that their business model and strategy are compatible with the transition to a sustainable economy and with the goal of limiting global warming to 1.5 °C, in line with the Paris Agreement. The (non-mandatory) IFRS Sustainability Disclosure Standards, effective for annual reporting from January 2024, also include standardised disclosures

15 Harmonising inputs and methods is part of the ongoing work of the ECB STC Expert Group on Climate Change Statistics, in which these type of issues are addressed by, for instance, providing transparent methodologies and relying on public sources such as the EU Emissions Trading System (ETS) and Eurostat Air Emissions Accounts (see **https://www.ecb.europa.eu/stats/ecb_statistics/sustainability-indicators/html/index.en.html**).

16 Large companies at first, with more companies that need to report over time. However, coverage for smaller, non-listed companies will most likely remain a persistent issue.

of forward-looking information on climate risks and opportunities. The Capital Requirements Regulation (CRR III) and the Capital Requirements Directive (CRD VI) will require banks to include in their supervisory reporting a prudential transition plan addressing risks related to environmental, social and governance (ESG) and indirect information on the alignment metrics of the financed sectors to the net zero emission target.[17] However, the exact guidance emanating from these legal texts is still being developed. In addition, other initiatives and alliances are emerging to develop frameworks and share best practices in order to meet the net zero targets, such as the G20's new Data Gaps Initiative (DGI-3, Recommendation 5) and the UNEP-FI Net Zero Banking Alliance.

3.1.1.3 Sovereigns

Climate change risks can negatively affect different stakeholders, from firms and households to the insurance and financial sectors, as well as public finances. Balance sheets are affected directly through increased expenditures for recovery or contingent liabilities, and indirectly through the impact on the real economy and the financial system. Increased contingent sovereign risks can arise from insufficient preparations and transition risks as well as more frequent and severe natural catastrophes (Figure 2). In addition, governments will face calls for subsidies, social adjustments and compensation. Beyond the sizeable investments needed to make the transition towards net zero and the costs for adaptation and damage repairs, public finances will be affected indirectly through lower tax revenues, materialising risks in the real economy and higher disaster losses. Sovereigns may further face contingent liabilities through the financial sector, especially via credit losses and explicit or implicit sovereign guarantees, though also through gaps in insurance coverage for which governments would be called to step in. These factors, in combination, can affect a sovereign's credit quality and debt financing ratios. The insurance sector can play a central role in managing the costs of climate-related disasters and by acting as an incentive to follow good practices and become less vulnerable through adaptation and mitigation measures. More precisely, the insurance sector has a role to play in addressing the protection gap e.g. by providing new insurance solutions, raising risk awareness and developing new risk transfer solutions.

The European Commission's Debt Sustainability Analysis (DSA) quantifies the impact on public finances of acute physical risks under 1.5 °C and 2 °C global warming scenarios.[18] The selected extreme weather events exert a direct negative impact on the primary balance in the year of the climate-related event and an indirect negative impact on GDP level and growth following empirical evidence of "no-recovery" effects (Batten, 2018; Hsiang and Jina, 2014). The assessment of the direct impact on public finances is based on the annual distribution of uninsured economic

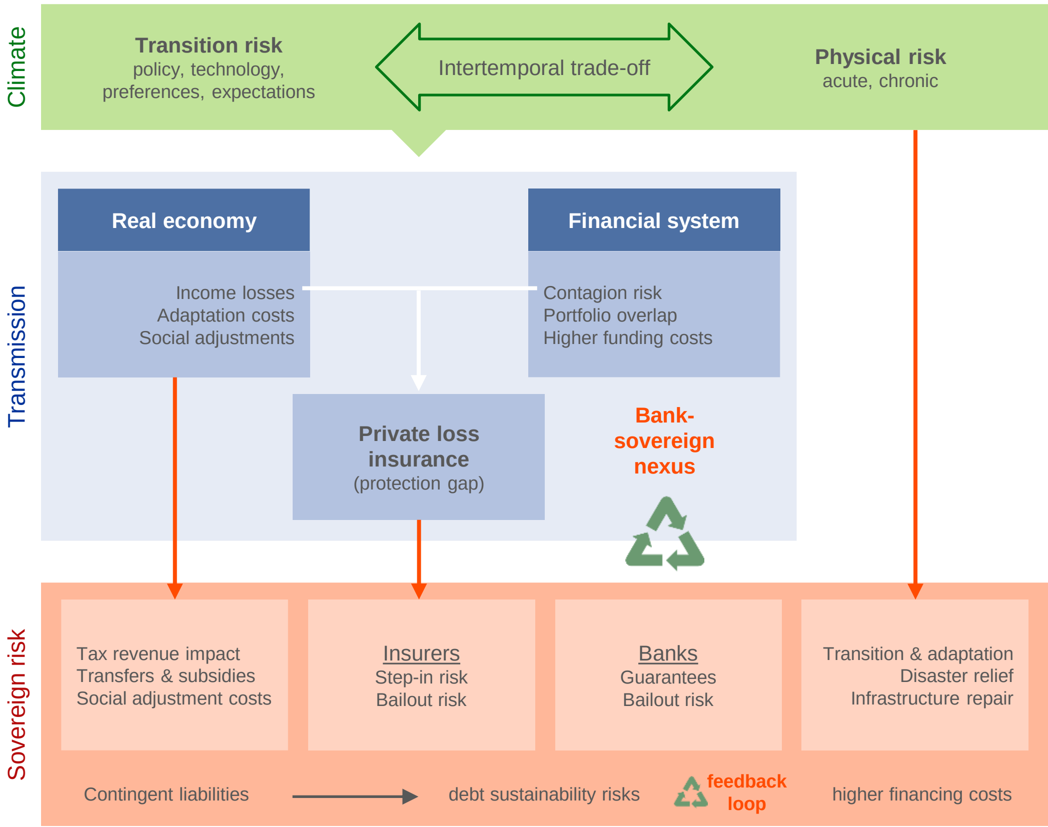
[17] The first data collected pursuant to CRR3/CRD6 will be reported in 2025. In the meantime, the EBA requires national competent authorities (NCAs) to collect data from significant institutions according to Decision EBA/DC/498 (first data will be submitted in 2024 with reference date 31 December 2023). In 2025 EBA will launch the Pillar 3 data hub, a public repository where ESG-related data collected under CCR3 will be available.

[18] See, in particular, Chapter 2, Part II of the Fiscal Sustainability Report 2021 (see European Commission, 2022) and the related Discussion Paper (Arevalo et al., 2022). This work has been conducted in line with the objective of "more systemic" adaptation of the new EU Strategy on Adaptation to Climate Change. The work provides sovereign debt projections for a set of vulnerable Member States: Spain, Romania, Portugal, Czech Republic, Hungary, Poland, Greece, Italy, Austria, France, Belgium, Germany and the Netherlands. The scenario is obtained via the Joint Research Centre (JRC) referring to the Paris Agreement targets, starting from baseline climate conditions and computing economic losses according to different global warming pathways. The scenarios differ from those of the Network for Greening the Financial System (NGFS). For more information, see Feyen et al. (2020).

losses from EM-DAT data[19] to capture the likely economic impact from warmer climate.[20] For the indirect impact, the climate events are assumed to reduce the annual GDP growth rate in the year of disaster by 0.5% relative to the baseline scenario and translate into permanently lower levels of GDP in the long term.[21]

Figure 2

Sovereign climate-related risks and link to financial stability



Source: ECB/ESRB Project Team.

19 EM-DAT is a global database with information on over 26,000 mass disasters from 1900 to the present day. For more information, please visit www.emdat.be.

20 The Centre for Research on the Epidemiology of Disasters (CRED) within the Université catholique de Louvain (UCLouvain) provides free access to the full Emergency Events Database (EM-DAT) for non-commercial purposes. For each country, the study identifies the maximum of that distribution as instance of a past tail event and multiplies the associated economic losses by a “Factor Increase”. The Factor Increase is obtained from the PESETA IV study of Feyen et al. (2020), which estimates expected economic losses from extreme events due to increasing levels of global warming under the Paris Agreement target levels of 1.5 °C and 2 °C.

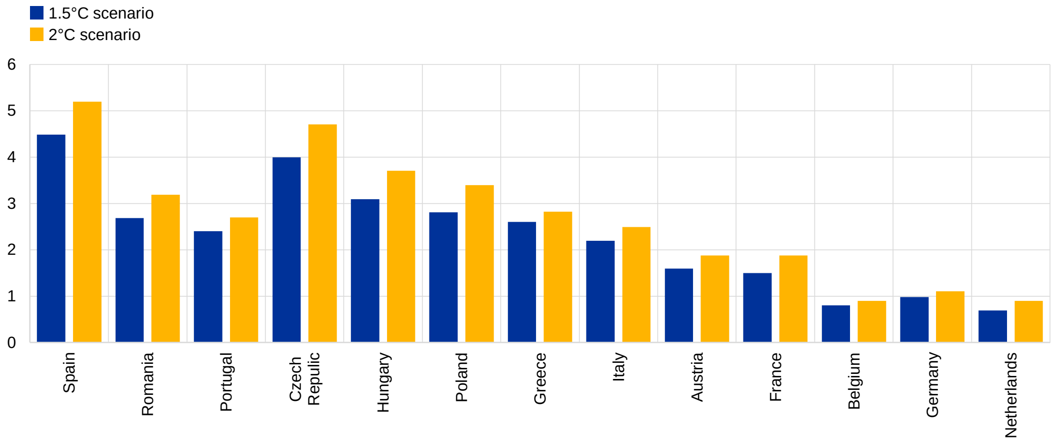
21 This assumption is derived from Fache Rousová et al. (2021), European Insurance and Occupation Pensions Authority (EIOPA). This is in line with the empirical evidence on the short- and long-term macroeconomic consequences of natural catastrophes and, notably, the “no-recovery” effects (Batten, 2018; Hsiang and Jina, 2014). According to this hypothesis, disasters affect economic growth by either destroying productive capital directly or by destroying durable consumption goods that are replaced using funds that would otherwise be allocated to productive investments. However, no rebound occurs, because the various recovery mechanisms above fail to outweigh the direct negative effect of losing capital (Hsiang and Jina, 2014; p. 7).

At the end of the projection horizon in 2032 and for the 1.5 °C scenario, the debt-to-GDP ratio increases by a minimum of 0.7 percentage points (p.p.) for the Netherlands to a maximum of 4.5 p.p. for Spain relative to the baseline (Chart 3). These impacts are non-negligible and heterogeneous across the debt projections of EU Member States and confirm the relevance of climate-related disasters as an additional source of risk to debt sustainability.[22]

Chart 3

Debt sustainability assessment following materialisation of climate-related shocks

(y-axis: percentage; debt-to-GDP projections as a % of GDP, relative to baseline, by 2023)



Source: European Commission.
Note: See Chapter 2, Part II of the European Commission Fiscal Sustainability Report for further details.

These debt sustainability impacts might be seen as a lower bound, given the potential for of contingent liabilities – both from financial and nonfinancial firms. Previous work has shown that, whether a government is obligated by law or simply forced by circumstances to provide public financing to cover contingencies, contingent liabilities can lead to large increases in public debt. In assessing episodes of contingent liability being realised between 1995 and 2014, [23] two features emerge. First, contingent liabilities have tended to emerge in waves around crises, where their materialisations added 5% of GDP on average to sovereign debt. Second, the largest fiscal costs related to public bailouts of state-owned enterprises stemming from implicit commitments – notably in the climate-relevant sectors of utilities, transport and industry. The prospect of such losses could, in turn, create scope for a sovereign-financial-corporate nexus.[24]

3.1.2 Financial institutions

Linking household and corporate climate exposures to financial institutions can provide insights into financial risk relevant for financial institutions. Table 3 provides an overview of

22 See Table II.2.6 in Chapter 2, Part II of European Commission (2022).

23 See Gardó et al (2021).

24 See ECB (2021d), **The sovereign-bank-corporate nexus – virtuous or vicious?** (speech by Isabel Schnabel).

exposure indicators for financial institutions that are novel or have been further developed since the previous report. Box 1 further below provides a first view into a new dataset on Energy Performance Certificates among euro area banks.

Table 3
New exposure indicators for financial institutions

Indicator	Key insights
Weighted Average Carbon Intensity (WACI) and Bank Carbon Footprint (BCFP)	Assesses exposure of the financial sector to high-emitting firms via loans and debt securities
Carbon-financing tilt	Credit-weighted emission intensity relative to a value-added-weighted emission intensity
Taxonomy alignment	Estimates the level of alignment of financial portfolios with the EU Taxonomy for sustainable activities
Concentrated emission exposures	Share of lending to certain sectors, or using a climate-weighted Herfindahl-Hirschman Index
Exposures to physical hazards: shift in return periods	Shift in return periods of river flooding for bank loan portfolios under different RCPs, expressed as a % of the number of debtors

Source: ECB/ESRB Project Team.
Notes: The list of indicators covers only indicators that are newly presented in this report. For a more comprehensive list of indicators, see separate Chartbook publication.

Exposure to transition risk via non-financial corporations

Weighted Average Carbon Intensity (WACI) and the Bank Carbon Footprint (BCFP) consider the exposure of the financial sector to high-emitting firms via loans and debt securities.[25] These indicators, developed by the Eurosystem Statistical Expert Group on Climate Change, provide information on the amount of bank financing of economic activities that may be affected by the transition to net zero.

WACI measures the loan-weighted exposure of the euro area banking system to carbon-emitting activities of non-financial corporations.[26] Between 2018 and 2020, WACI, expressed as direct emissions per firm revenue[27], remained broadly stable over time despite considerable dispersion across countries, as measured by the range between the 90th and 10th percentiles across euro area countries (Chart 4). Notably, changes over time are driven by offsetting effects in

[25] For further information, please refer to ECB (2023b). The end point of the time series is such due to data availability issues. Notably, more up-to-date data are expected in the upcoming publications.

[26] WACI with regard to securities takes the perspective of financing global groups via equities and securities and thus accounts for global Scope 1 emissions. The loan indicator takes a single entity perspective and considers only euro area lending to euro area debtors.

[27] Notably, in their current form, the STC Expert Group analytical carbon emission indicators only consider backward-looking emissions. Annex **Error! Reference source not found.**below discusses a measure for the forward-looking WACI using d ifferent input data and methodologies.

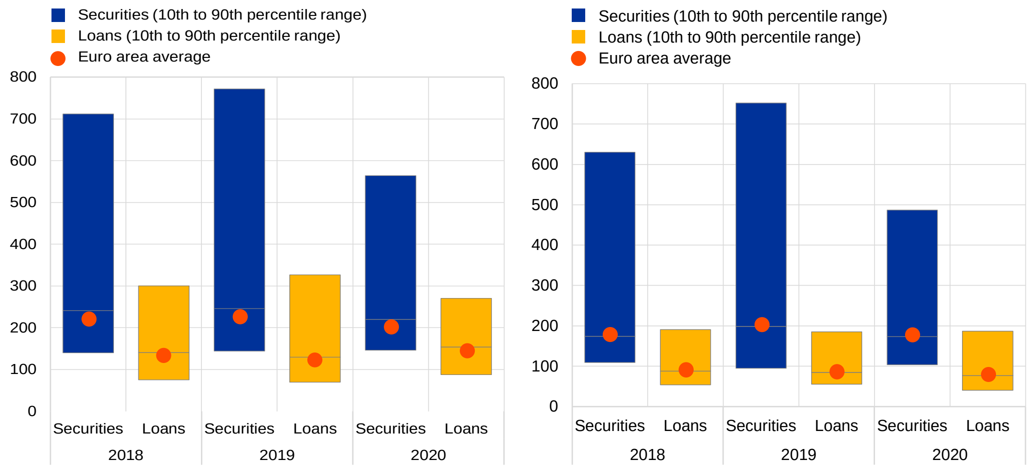
the indicator components (emission intensities and loan weight), which however need to be interpreted with care due to the analytical nature of the indicators.[28]

A companion BCFP indicator normalises firms' financed GHG emissions by the respective outstanding loan or securities volume, thereby capturing the GHG impact of their financing. However, in contrast to WACI, BCFP direct GHG emissions are not standardised by a measure of firm output and thus do not account for how efficiently these emissions are used by counterparties to generate their goods and services. In addition, the indicator fails to capture the GHG impact of firms with low levels of external financing. The euro area BCFP figure remains broadly persistent over time with considerable cross-country dispersion. The findings suggest that loan and securities exposures of banks to high-emitting economic activities remained prevalent during the period under consideration, despite banks striving to reduce transition risks.[29]

Chart 4
Exposures of the financial sector to high-emitting firms via loans and debt securities

a) Scope 1 WACI | *b) Scope 1 Bank Carbon Footprint (BCFP)*

(y-axis: tonnes of CO2e per million euro) | *(y-axis: tonnes of CO2e per million euro)*



Sources: Statistics Committee Expert Group analytical carbon emission indicators based on data from AnaCredit, Securities Holding Statistics (SHSS), ISS, Refinitiv, EU Emissions Trading System (EU ETS), Eurostat Air Emissions Accounts (AEA) and Orbis by Bureau van Dijk.
Notes: The chart illustrates the euro area Bank WACI (panel a) and Bank Carbon Footprint (CFP, panel b) of deposit-taking corporations (S122) via loans (yellow) and securities, i.e. debt and equities (blue).
The range bars indicate the cross-country range between 90th and 10th percentiles. Both panels show only Scope 1 emissions. WACI measures weighted carbon intensity with respect to revenue: total GHG emissions of a debtor relative to its revenues, weighted by the investment in these activities as a share of the total investment portfolio value covered with emission and financial information; Carbon footprint measures financed emissions with respect to assets: financed emissions standardised by the total investment portfolio value covered with emission and financial information.

[28] Relative metrics like the WACI are less sensitive to compositional changes over time, as opposed to absolute indicators, but particularly sensitive to outliers in the components, such as firm revenues.

[29] To account for changes in the total amount of investments over time, the BCFP is standardised by the subset of total investment portfolio value covered with emission and financial information which also feeds into the calculation of financed GHG emissions among firms.

Carbon-financing tilt

Carbon-financing tilt (carbon tilt) measures credit-weighted emission intensity relative to a value added-weighted emission intensity. It provides information on how strongly credit granted to NFCs by financial institutions is tilted towards counterparts with high emission intensity relative to the structure of the economy, measured by gross value added (GVA).[30] If measured as a percentage of the GVA-weighted emission intensity, a positive value of the tilt indicates that bank credit is tilted towards more carbon-intensive exposures relative to the GVA structure of the economic activity.

Chart 5

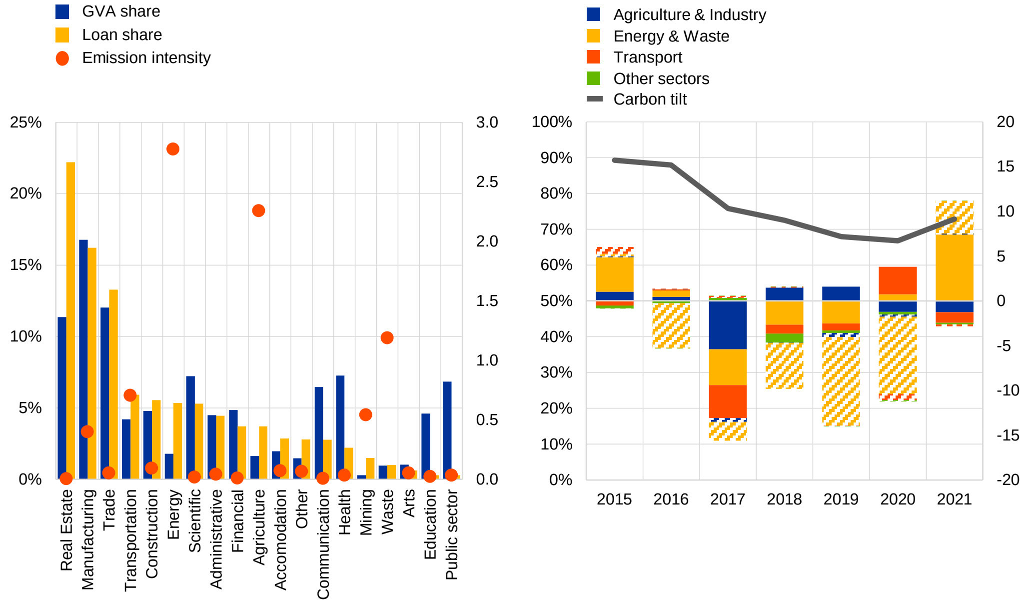
Euro area bank lending towards emission-intensive sectors

a) Bank loan portfolio tilted towards emission-intensive sectors

(y-scale: percentage; right-hand scale: Kg CO2e / EUR)

b) Carbon tilt (LHS) and decomposition of annual change into lending volume and emissions intensity by sector (RHS)

(y-scale LHS: percentage; RHS: percentage points)



Sources: Eurostat, ECB Consolidated Banking Data and ECB calculations.
Notes: The carbon tilt is the ratio between loan-weighted emission intensity and GVA-weighted emission intensity. The decomposition of over time stems from changes in the emission intensity of each sector as well as relative changes in the share of loans or share of GVA of the respective sector, and from lending shift to carbon-intensive sectors (relative to the change in GVA). The filled area of the bars (panel b) represents the lending shift towards carbon-intensive sectors, while the shaded area represents emission intensity.

[30] The metric can be applied at the firm, sector or country level, whereby the emission intensity would be aggregated by weighting by revenues, gross value added or GDP. The credit-weighted emission intensity can be computed either with total credit or bank loans only (or another financial instrument).

Bank loan financing is 73% more emission-intensive than economic activity when weighted by value-added.[31] Based on 2021 Eurostat Scope 1 emissions by NACE Rev. 2 sector, euro area loan-weighted emission-intensity is 0.38 kg CO2e per EUR GVA, compared to 0.22 for the GVA-weighted measure. The tilt is especially driven by lending to the transportation, energy and agriculture sectors. These industries combine high emission intensities, account for sizeable shares of the loans portfolios of euro area banks , and have loan shares that are larger than their contribution to euro area GVA (Chart 5, panel a).

The annual change in the carbon tilt shows a decline from 2015 to 2020 and a slight uptick in 2021 (Chart 5, panel b). The downward contributions stem primarily from a reduction in emission intensity of the real economy from 2018 to 2020, whereas the increase in 2021 is driven to a similar extent by an increase in emission intensity within sectors and by a stronger shift of loans towards the more carbon-intensive sectors. A further analysis reveals that the decline between 2018 and 2020 was driven by lower contributions from energy, waste and transportation, whereas the increase seen post-Covid in 2021 was down to the energy and waste sectors, mainly due to a stronger shift of credit towards these sectors relative to the increase in GVA. The rise in emission intensity for these sectors also contributed to the increase in the carbon tilt, albeit to a lesser extent.

Taxonomy alignment and shift of transition risk

The portfolios of European investors have become greener in real (absolute) terms but less green in terms of (relative) share of holdings, and the same has happened with respect to their exposure to transition risk. Based on the Taxonomy-Alignment Coefficients (TACs) and Transition-risk Exposure Coefficients (TECs) developed by Alessi and Battiston (2023) and applied to ECB Securities Holdings Statistics (SHS), the amount of holdings aligned with the EU Taxonomy for sustainable activities grew slightly in real terms from €254 billion to €303 billion from 2014 to 2023, while holdings exposed to transition risk increased from €850 billion to €1.1 trillion (Chart 6). However, in percentage of total holdings, Taxonomy-aligned (TA) holdings decreased from 3.9% to 3.3% and transition-risk exposures (TE) fell from 13.0% to 12.1%.

Transition risk may be shifting to less regulated parts of the financial system. TE among OFIs has more than tripled, climbing from 5.5% in 2014 to 18.3% in 2023, as a share of total TE across investors (see also Alessi et al., 2023). Across all sectors, the TE portfolio share is higher than the TA portfolio share, highlighting ample room for improvement, and with general increases for OFIs (from 6% to 23%) and banks. While the distribution of TA and TE may largely vary across countries for a given investor class (See Annex 1), it is possible to identify clusters of countries/sectors presenting similar TA and TE values. Average TA and TE values for a given investor class in a given country provide reference values against which the performance of specific portfolios can be benchmarked.

---

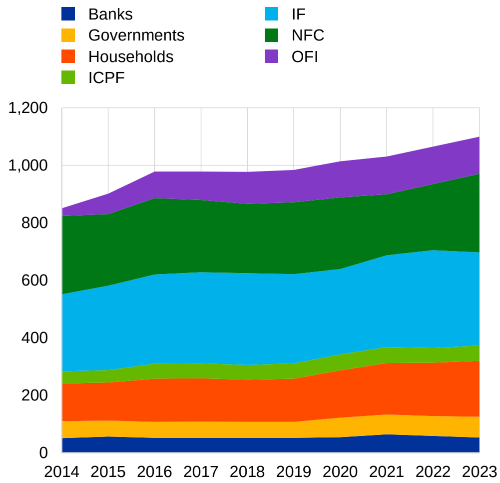
[31] The carbon tilt reveals that, on average, banks lend to firms with an emission intensity 73% higher than the economy's average.

Chart 6

Trend in investor exposure to transition risk

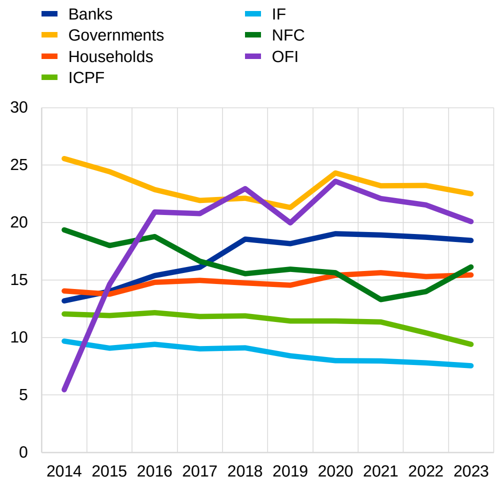
a) Exposure to transition risk in absolute value

(y-axis: EUR billion)



b) Exposure to transition risk as share of investors' portfolios

(y-axis: percentage of sector assets)



Source: Alessi and Battiston (2023).
Notes: Panel a): values reported are in real terms (in 2023 euro). Panel b): TA and TE shares are obtained as ratios of TA or TE holdings over the value of the holdings of a given investor class. The calculations are based on SHS; last datapoint refers to Q1 2023. ICPF = Insurance corporations and pension funds; IF = Investment funds; NFC = Non-financial corporations; OFI = Other financial institutions.

Box 1
Energy performance certificates in euro area banks

In recent years, European regulators and supervisors have developed and implemented a dedicated climate disclosure framework for euro area banks, including the ECB's Guide on climate-related and environmental risks, European Banking Association (EBA) technical standards on Pillar 3 disclosures for ESG risks, and the CSRD[32].

In 2023 euro area banks published their first ESG Pillar 3 disclosures according to the EBA's technical standards, including figures on the energy performance certificates (EPC) of real estate used as collateral for loans.

An initial assessment of these figures suggests that not all banks possess EPC data for collateralised commercial real estate (CRE) or residential real estate (RRE) exposures. In addition, banks still rely heavily on estimated or proxied[33] EPC data. A comparison of the data disclosed for commercial and RRE suggests that the availability of actual EPC data varies across the different

[32] The quality assurance of the disclosures of the EBA ITS templates on P3 data with reference date at year-end 2022 is still work in progress and any conclusions/figures are subject to change.

[33] While such use of estimates or proxies is allowed under EBA standards, banks that use estimates or proxies are required to explain the extent of use of estimates or proxies and the kind of estimates applied.

types of collateral. For loans collateralised with CRE, most banks possess some information on the EPCs of the underlying collateral; with at least two thirds of disclosing banks relying on actual EPC information[34]. However, EPC data availability still varies across countries and depends also on national regulations. For loans collateralised with RRE, the availability of EPC data generally appears to be more heterogeneous across banks[35] and a larger number of banks did not report the respective information in their first disclosure. Going forward, banks are expected to make further efforts to improve their climate-related disclosures, considering also the forthcoming regulatory developments in this area.

Concentrated emission exposures in the banking sector

Beyond the size of exposures to the materialisation of transition risk, their concentration may force individual banks to face disproportionally large losses. ECB (2022c) identified carbon-related concentration risk as a threat to financial stability, which finds further support from the central bank's 2022 bottom-up climate risk stress test, which revealed that more than 60% of the interest income of euro area significant institutions comes from NFCs operating in 22 relevant carbon-intensive sectors, including real estate, construction, and the wholesale and retail trade. Meanwhile, the Basel Committee on Banking Supervision issued a recommendation stating that banks should quantify and manage climate-related concentration risk (Basel Committee on Banking Supervision, 2022).[36]

Corporate lending and transition losses are concentrated in manufacturing, construction, the wholesale and retail trade, real estate, and professional, scientific and technical activities (Chart 7, panel a). While these sectors represent only 54% of euro area GVA, they accounted for 70% of euro area corporate lending at the end of 2022 and represent 61% of estimated potential transition losses within the ECB's 2023 top-down economy-wide climate stress test.[37] Moreover, banks' interest income is concentrated among high-emitting sectors, with 21% coming from highly GHG-intensive sectors, with more than 1,000 tonnes of CO2 per € million in revenues.[38]

Carbon-related concentration risk can be measured using a climate-weighted Herfindahl-Hirschman Index (cwHHI). The cwHHI is an adaptation of the conventional Herfindahl-Hirschman Index to show lending concentration by individual banks. It is based on a bank's corporate lending activities and borrowers' individual fossil fuel consumption. The cwHHI computes the degree of portfolio concentration where loans to borrowers that are more vulnerable to transition risk – as proxied by their fossil fuel consumption – receive a higher weight. The cwHHI not only measures current transition risk-based concentration risk but also allows for forward-looking carbon-related

[34] Except for one country where no EPC information is provided.

[35] Except for one country where no EPC information is provided.

[36] In addition, the European Banking Authority (EBA 2022) launched a public consultation on how to address climate-related concentration risk.

[37] Emambakhsh et al. (2023).

[38] ECB (2022a).

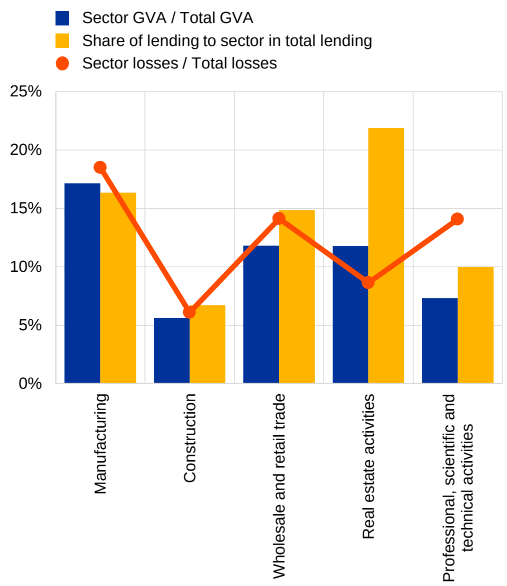
concentration risk assessment, by projecting fossil fuel consumption into the future based on Network for Greening the Financial System (NGFS) scenarios and sector-level data.[39]

Chart 7

Carbon-related concentration risk

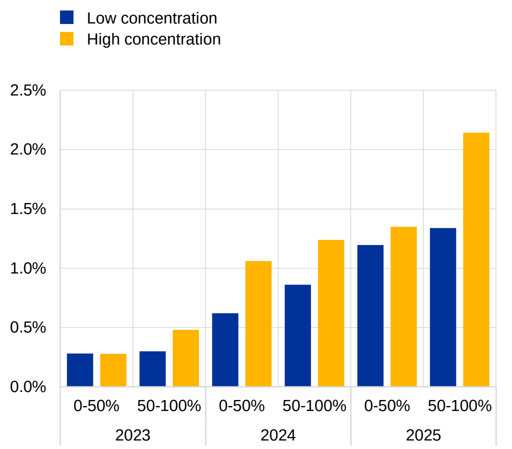
a) GVA, lending and transition risk losses by sector

(y-axis: percentage share)



b) Transition risk losses due to concentration risk among banks with similar transition risk exposures

(x-axis: percentile range of share of portfolio allocated to high fossil fuel consumers by year; y-axis: average losses in accelerated transition scenario as a percentage of corporate loan portfolio)



Sources: AnaCredit, Urgentem, iBach, Eurostat and ECB calculations.

Notes: Losses are calculated on the basis of the accelerated transition scenario of the 2023 top-down climate stress test. The sample contains 103 euro area Sis; data in panel a refer to 2022, except for Eurostat GVA data on NACE level 2 which were only available for 2021. Bank-level climate-weighted Herfindahl-Hirschman Index (cwHHI) scores are calculated using borrowing firms' fossil fuel consumption projections. A firm is classified as a high fossil fuel consumer if it scores above the 75th percentile of fossil fuel consumption in the distribution of unique firms. Note that the reason that projected losses are higher than GVA or loan shares in the sector professional, scientific and technical activities is that this sector (also) consists of holding companies with subsidiaries in high-polluting sectors (Scope 3).

Carbon-related portfolio concentration is associated with higher transition losses even when overall transition risk is held constant (Chart 7, panel b). We compare projected annual transition risk losses between banks with above and below median cwHHI, separately for the top and bottom 50% of banks based on the share of their portfolio allocated to firms with high fossil fuel

[39] When fossil-fuel consumption is not available for a borrower, data can be inferred based on the borrower's subsector and revenue. To project fossil fuel consumption into the future, each sector is then assumed to cut its fossil fuel consumption in line with the respective NGFS scenario under analysis (such as an accelerated transition).

consumption (as a measure of transition risk).[40] Within both the top and bottom 50%, banks with high concentration levels face substantially larger losses than their more diversified peers when facing a transition shock.[41] These findings confirm that concentration risk cannot simply be lumped in with transition risk. Moreover, concentration and transition risks seem to reinforce each other. While the least concentrated banks with the lowest transition risk exposures record losses of only 1.20% or so of their corporate loan portfolio by 2025, the most concentrated banks with the highest transition risk exposure record losses totalling 2.14% of their corporate loan portfolio – around 60% higher than the losses of banks not exhibiting such high concentrations. The higher the degree of transition risk, as proxied by banks' lending to heavy fossil fuel consumers, the higher the losses due to concentration risk. Hence, transition and concentration risk may amplify one another.

Exposures to physical hazards: shift in return periods

Riverine flooding also poses a significant risk for banks in areas of high exposure, as flooding has historically been the most relevant type of physical risk in Europe. The sift in return periods captures increased frequency of occurrence for a specific natural disaster. Chart 8 below shows expected intensification in flooding looking ahead to 2055 in the loan portfolios of euro area banks towards non-financial firms. For instance, at a specific location[42], flood intensity, which is currently expected to occur once per 100 years (indicated by a vertical line on Chart 8a), is expected every 60 years under RCP 4.5 and every 40 years under RCP8.5 (represented by leftward shift in the distribution, Chart 8a). Chart 8 (panel b) shows the most affected countries where this information is linked to bank loan portfolios. In Belgium, France and Luxembourg, over 80% of loan exposure is towards companies located in areas where frequency of flooding more than doubles (from every 100 years to up to 50 years) under the most pessimistic climate scenario. Note that the Netherlands and Germany will experience intensification of flood risks according to the models used. However, risks will diminish when flood defences are accounted for; in the Netherlands many areas are protected against floods for a return period of up to 1,000 years. Moreover, certain countries will experience less frequent flood events, especially Portugal, Greece and Spain, due to their increased vulnerability to droughts and water stress.

---

40 Transition risk losses (accelerated transition scenario) for the 2023-2025 period are taken from the ECB's 2023 top-down climate stress: Emambakhsh et al. (2023).

41 Results are qualitatively similar when splitting banks based on quintiles of transition risk instead of top/bottom 50%.

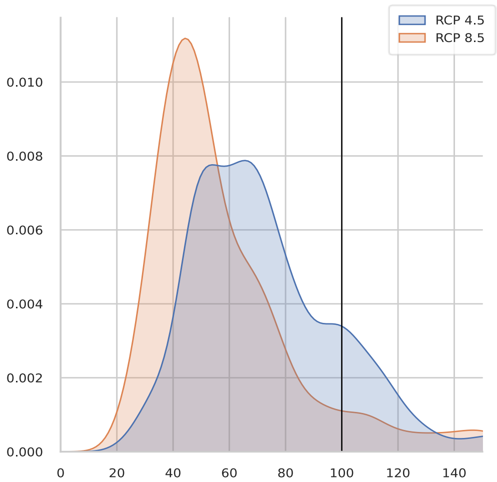
42 Flood risk is estimated at the registered address of each debtor, although future work will look to more reliably identify the location of a firm's assets (e.g. production plants).

Chart 8

Exposure to river floods under different climate scenarios

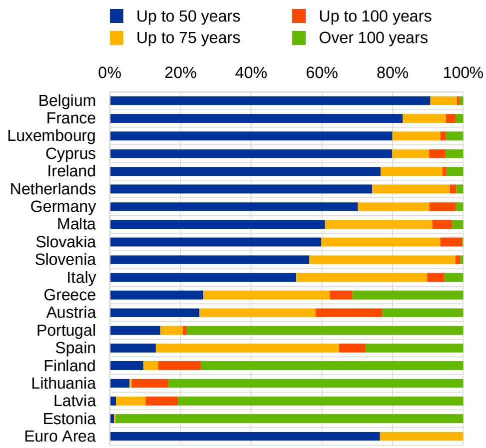
a) River flooding – shift in return periods for bank loan portfolios under different RCPs

(y-axis: probability distribution, number of debtors in loans portfolios of euro area banks, projection for 2050; x-axis: Shift in flood return period (base = 100 years)



b) Bank loans portfolio exposed to river flooding –shift in return period

(breakdown by creditor country, Dec 2020, base 100 years return period, RCP8.5, projection for 2050)



Sources: ECB calculations based on data from analytical credit datasets (AnaCredit) and Joint Research Centre (JRC). Flood risk projections are based on Alfieri et al. (2015).
Notes: The graph displays shift in return periods under RCP4.5. and8.5 scenarios based on an initial return period of 100 years for bank loans portfolios. The left panel represents probability density functions (PDF, kernel density estimation) of the shift in 100-year return period under the RCP 8.5 climate scenario at the location of non-financial companies with loan exposures (the vertical line indicates the 100-year baseline, while the leftward shift from the baseline indicates an increased frequency of flooding of a certain intensity in company's location). The right panel shows the share of loans exposed to a certain increase in probability split into four brackets (1-50, 51-75, 75-100 and over 100 years). AnaCredit data are for December 2020.

3.2 From exposure to risk and vulnerability metrics

This section builds on previous reports and presents new forward-looking and localised risk metrics for banks, as well as insights into the effect of climate risk on public finances and insurance premiums. Previous reports introduced several metrics to assess risks and vulnerabilities for financial institutions and applied them in a static, not forward-looking way. Notably, ECB/ESRB (2022) described the Transition-to-credit risk intensity (TCI), combining loan exposures among banks with emissions and probabilities of default (PD) among firms. Moreover, the bank-level climate risk sensitivity (CRS) metric captures the relative increase in expected losses triggered by an increase in carbon prices. The report also presented what it calls physical-to-credit risk intensity (PCI), which accounts for the physical dimension of climate risk.

3.2.1 Banks

3.2.1.1 Forward-looking indicators

To ensure the successful monitoring of climate-related risk, it is important to integrate forward-looking information into the metrics, as backward-looking information does not provide a comprehensive picture on exposures and vulnerabilities to climate risk. Depending on the trend in global temperatures and CO2 emissions, current exposures and vulnerabilities to climate-related risks may or may not correspond to the exposures and vulnerabilities looking further ahead. Therefore, it is paramount that supervisors take a forward-looking perspective in assessing and weighing the risks and vulnerabilities of different climate pathways and their consequences for financial stability. Forward-looking exposure and vulnerability metrics for transition risks are calculated for banks' corporate loan books under a "sudden transition scenario".[43] The metrics presented in this chapter are sourced from the previous ECB/ESRB Project Team report and are computed with forward-looking balance sheet and transition risk components based on projections from the latest ECB top-down climate stress test.[44]

Transition-to-credit risk intensity (TCI) among banks is expected to surge at the onset of a sudden transition scenario due to heightened credit risk but would quickly recover in response to timely emission reduction efforts. TCI serves to identify bank vulnerability towards combined transition and credit risk via their loan portfolios.[45] TCI would triple at the euro area level between 2022 and 2023, at the onset of the sudden transition scenario, and remain high until 2024. However, from 2025 onwards it would quickly recover and by 2027 reach half of its value relative to 2024. The prompt fall-back is mainly due to the rapid reduction in emission intensities from 2023 onwards, even though probabilities of default are expected to remain high (Chart 9, panel a).

The climate risk sensitivity metric measures the sensitivity of banks' corporate loan losses to a future increase in carbon prices.[46] Corporate loan losses among banks due to rising carbon prices in a sudden transition are only partially correlated with emissions among borrowers and are highly concentrated (Annex 1.4.3). Vulnerability towards carbon prices is highly concentrated among relatively few banks. By 2027, around a quarter of total loan portfolios already comprise around 50% of total additional losses due to carbon prices (Chart 9, panel b), showing that close

---

43 Detailed information on the scenario narrative and methodology can be found in Section 2 of this report. In a sudden transition scenario, banks' exposures to transition risk halves by 2030 while rising carbon prices cause heightened credit risk at the onset. Exposure to transition risk falls by almost 50% until 2030 due to rapid emission reductions and steady economic growth.

44 See ECB/ESRB (2022) and Emambakhsh et al. (2023).

45 TCI is calculated at loan level and aggregated at bank portfolio-level. For a bank j and loan i, TCI is defined as: $TCI_j = \sum_i (PD_{ij} * Co2\ emissions\ intensity_i\ x)$. PDs correspond to probabilities of default and emission intensities are defined as absolute emissions over total revenues. The forward-looking information used to calculate TCI comprises projections of firm-level balance sheet information and emissions (revenues and Scope 1, 2 and 3 emissions), and firm-level PDs, as projected using the ECB top-down climate stress test.

46 The increase in corporate loan losses stemming from carbon price increases is calculated for each credit exposure of each corporate loan portfolio as: $\sum_t \frac{expected\ losses_{t0}}{EAD_{t0}} x \left[\beta_{P,s} x \Delta(profitability)_t + \beta_{L,s} x \Delta(leverage)_t\right]$, where $\beta_{P,s}$ and $\beta_{L,s}$ are sector-level coefficients determining the extent to which borrower PDs react to changes in profitability and leverage, based on the credit risk model of the **second ECB top-down climate stress test** (Emambakhsh et al., 2023). $\Delta(profitability)_t$ and $\Delta(leverage)_t$ indicate the projected year-on-year change in firm-level profitability (due to higher operating expenses) and leverage (due to higher green investments) due to rising carbon prices.

attention should be paid to a specific subset of banks and exposures once transition risk materialises.

Chart 9

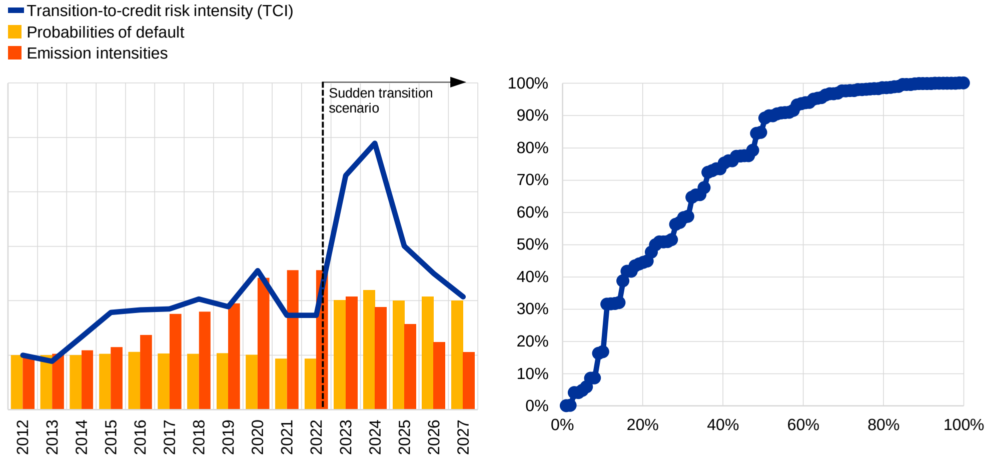
Bank vulnerability towards transition risk and its concentration within the financial system

a) Evolution of transition-to-credit risk TCI components over time under a sudden transition scenario

(y-axis: index; 2012 = 1)

b) Banks' cumulative share in additional expected losses by 2027 under a sudden transition scenario, ranked from highest to lowest Climate risk sensitivity (CRS)

(y-axis: cumulative share of expected losses as a percentage, x-axis: share of banks as a percentage)



Source: ECB calculations based on Orbis, Urgentem (acquired by ICE), Eurostat, IRENA, Intergovernmental Panel on Climate Change (IPCC), BMPE macroeconomic projections, NGFS, Register of Institutions and Affiliates Database and AnaCredit.
Notes: More details on the sudden transition risk scenario can be found in Section 2.3.. Panel a): The time series covers both inferred and reported emissions for 1,250 non-financial corporations (NFCs), which comprise on average 10% of AnaCredit exposures over time. The backward-looking results of TCI assume that the credit risk component (PD) does not already consider climate risk. The components of the forward-looking TCI are assumed to follow the pathway of the sudden transition scenario. Two different underlying sources for emissions data are used. Historical TCI uses emissions based on firm-level data from Urgentem (acquired by ICE). The forward-looking emission intensities refer to firm-level Scope 1, 2 and 3 absolute emissions over revenues as of 2021 from Urgentem and projected forward according to the implied country-sector emission pathways of the sudden transition scenario and firm-level projection of revenues. Panel b) presents the results for corporate loan portfolios of euro area significant institutions (SIs).

Exposure to wildfire and flood risk is expected to remain high until 2050, with the largest exposures towards high flood risk though with rising exposures also towards high wildfire risk. Acute physical risk exposure is not particularly concentrated across sectors (Chart 10, panel a). However, more than 50% of total loan exposures towards the mining, water supply and wholesale sectors are affected by extreme flood risk, while more than 10% of exposures towards the mining sector are affected by extreme wildfire risk. Acute physical risk exposures are expected to increase by up to 3.5% until 2050, especially in the manufacturing, water supply and construction sectors.

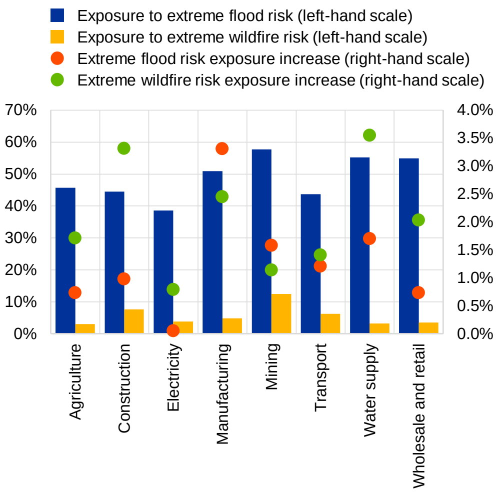
PCI is concentrated in a few sectors and does not fully overlap with the simple physical risk exposure metric. PCI serves the same purpose as TCI but identifies combined physical and credit risks.[47] The construction, manufacturing, transport and wholesale and retail sectors present the highest physical-to-credit risk intensity for both flooding and wildfire risks. In addition, the mining sector is particularly exposed to high wildfire-to-credit risk intensity. There is a considerable difference in the ranking of sectors between the PCI and the simple risk exposure metrics. While the wholesale sector has the highest share of exposures being exposed to extreme flood risk, it ranks only fourth in its flood-to-credit risk intensity. At the same time, the construction sector has considerably less exposures affected by high flood or wildfire risks. However, it is the most exposed sector in terms of physical-to-credit risk intensity.

Chart 10

Bank vulnerability towards physical risk and its overlap with sector exposures towards physical risks

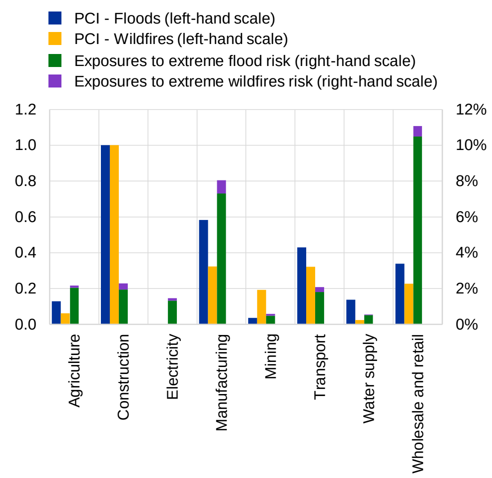
a) Sector-level exposures towards borrowers extremely exposed to floods and wildfires in 2030 and change in exposures by 2050

(left-hand scale: share of sector-level exposures in 2030; right-hand scale: increase in sector-level exposures by 2050)



b) PCI is concentrated among sectors and only partially overlaps with the share exposures towards extreme floods and wildfire risks

(left-hand scale: min-max normalised PCI; right-hand scale: share of vulnerable to total corporate loan exposures in percentages)



Source: ECB calculations based on Moody's 427, Register of Institutions and Affiliates Database and AnaCredit.
Notes: Exposure to flood and wildfire risk is measured via forward-looking risk scores from Moody's 427. These normalised scores range from 0 to 100 and measure the frequency and intensity of the respective hazard based on a firm's geographical location at address level. Firms are categorised as tail risk firms for floods (wildfires) if their flood (wildfire) score is above 75 (50). Sectors refer to NACE Level 1 letters. "NACE" stands for Nomenclature statistique des activités économiques dans la Communauté Européenne (Statistical classification of economic activities in the European Community).

47 The PCI is calculated at loan level and aggregated at bank portfolio-level. For a bank j and loan i, the PCI is defined as: PCI_j=∑_i PD_ij*physical risk score_i x (loan exposure_i /∑_i loan exposure_i). PDs correspond to probabilities of default and forward-looking physical risk scores were used for the years 2030, 2040 and 2050 from Moody's 427 for firms' flood and wildfire exposures at address-level.

3.2.1.2 Localised climate risk in bank portfolios

Localised climate risk and small business lending

Climate-related disasters and extreme weather events may have disruptive short- and medium-term consequences for firm operations, while their full impact is likely to materialise only in the long run (IPCC, 2022a, Fatica et al., 2022). The effects transmit also through the financing channel, when banks price in climate physical risk in financial products (Correa et al., 2022). SMEs tend to operate locally and rely heavily on bank credit, making them vulnerable to natural hazards. A natural disaster has a direct impact by destroying their physical capital and business activity and affecting local lenders (Bellia et al., 2023a). The bank credit channel may act as an important propagation mechanism, as physical damage reduces the value of collateralised assets and business disruptions make it harder for firms to honour their debt obligations.

High flood risk is generally priced into new loans, although to an extent that might not fully reflect the risks. Based on granular data for securitised loans, Barbaglia et al. (2023) find that loans originated in regions exposed to high flooding risk bear a slightly higher interest rate than loans to firms in less risky areas. This result is robust even when accounting for the recent materialisation of a flood. The size of the flood risk premium is higher for loans to micro and small businesses, as well as for those extended by cooperative and savings banks. Reflecting physical climate risk in the prices of bank credit leads to an increase in the cost of capital, in line with the recent evidence on US regional bond and equity markets (Acharya et al., 2022).

Flood episodes have a sizeable impact on loan default probability among small and medium-sized firms by impairing their ability to service debt. In the two years following a disaster, firms exposed to a flood – both in high-risk and other regions – are up to 30% more likely to default (30% higher PD) on their loans than firms located in non-flooded areas. Due to physical capital destruction and persistent business disruptions, disaster-exposed firms may exhaust their financial buffers to cushion the negative shock and run into liquidity and solvency issues in the medium term. This direct effect adds to the indirect effect of a higher interest rate as an important determinant of loan default, after which banks incur losses or have to write off loans to firms located in areas impacted by natural disasters.

Localised climate risk: a pilot study for German regional banks

The risk of capital destruction and reduced profitability from natural hazards poses challenges for debt repayment among firms and has repercussions for the financial sector.[48] This pilot stress test exercise evaluates the effects of localised climate-related events on regional banks operating exclusively within specific regions of Germany, thus helping to shed light on potential vulnerabilities in the German banking sector.

[48] Based on Bellia et al (2023a).

The study focuses on 670 cooperative banks, which are geographically more concentrated in their exposures, given their strong connection to the local economy compared to other types of banks. Based on ECB (2023a), under the current level of physical risk (baseline scenario), the size of German bank assets at risk due to river floods is 0.6% of their total loan book to NFCs.[49] As exposure to flooding varies within the country, we distribute the amount of assets across different NUTS 2 regions[50], using the share of people exposed as obtained from the Risk Data Hub. To account for the strain on bank loan portfolios that can arise from the impact of river flooding events, we consider the assets exposed to climate-related risks as non-performing loans (NPLs).[51] Climate change type scenarios, such as a 1.5 °C or 3 °C increase in temperature, are also considered, increasing NPLs proportionally to flood-related economic losses as estimated in Peseta IV (Chart 11, panel a).[52]

A micro-simulation portfolio model[53] based on individual bank balance sheet data is used to derive the loss distribution for the banking sector, considering a situation in which losses from physical risk (NPLs) coincide with initial financial sector losses.[54] Two cases are considered: (a) a crisis type situation, where the impact of physical risk coincides with an existing financial/economic crisis; (b) a normal economic situation, where the financial impact on banks comes solely from the physical risk, the materialisation of which triggers a small depreciation of the assets exposed, as modelled via a dynamic balance sheet.

Losses from flood-related risks appear to be contained under the baseline, even when the banking system is itself weakened by a financial crisis and when considering amplification from fire sale mechanisms. The situation becomes more worrying under climate scenarios. Coinciding with a crisis event, losses based on the simulation range from 0.4% to 0.9% of total assets for the 1.5 °C and 3 °C scenario, respectively.[55] For comparison, the loss impact of flood risks in normal times amounts to 0.2% (1%) of total assets under a 1.5 °C (3 °C) temperature increase and is strongly heterogeneous across German regions (Chart 11, panel b). The results show, under the constant balance sheet assumption, that adaptation strategies are effective in reducing the consequences of temperature increases, thus mitigating losses to levels comparable to what we might experience now (baseline).

49 **PEAR indicator** (potential exposure at risk).

50 While having more granular data (at NUTS 3 level, for example) would allow us to estimate more reliably the potential losses due to physical risk, we assume in our analysis that a given cooperative bank is lending at NUTS 2 level. These regions might be quite large in terms of area, and only a fraction of the total assets present within the region might be affected by an acute physical risk. However, due to data limitations, we retain this assumption, on the understanding also that a business area or regional bank might be smaller than NUTS 2 areas but larger than NUTS area.

51 When borrowers are affected by catastrophic events involving losses and damage to their businesses, they are unable to honour their debt obligations, resulting in an increase in unlikely-to-pay and non-performing loans. This is also one assumption of the stylised model, since part of the losses from NPLs might be recovered, perhaps due to the enforcement of collateral.

52 For the 3 °C temperature increase scenario, we also consider the case where adaptation measures are in place.

53 Known as the Systemic Model of Banking Originated Losses (SYMBOL); see De Lisa et al (2011).

54 The framework subsequently examines whether the bank's capital is high enough to absorb physical risks or whether the bank's failure could potentially lead to further failures within the banking sector.

55 The full results for the baseline and for the various scenarios are not presented here for brevity, but can be found in Bellia et al. (2023a).

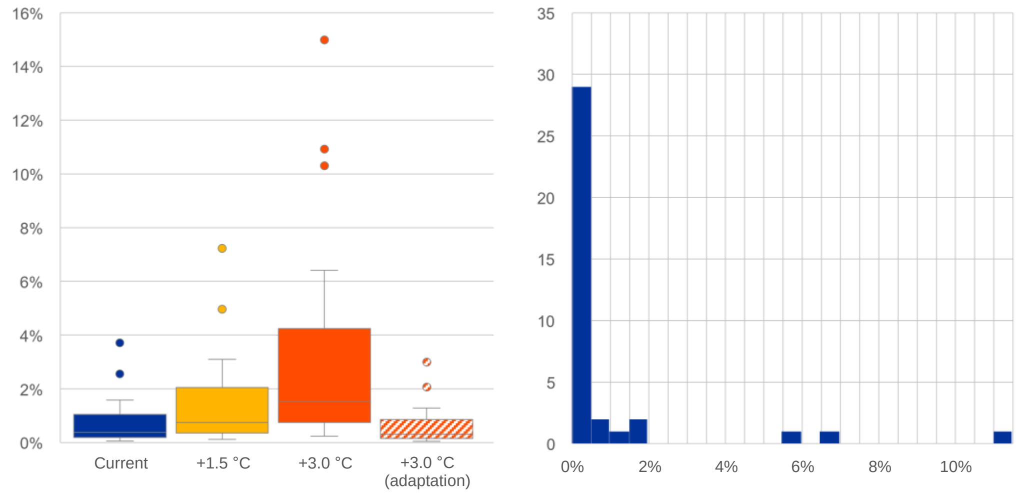
Chart 11

Consequences of climate changes across German regions: share of bank assets at risk and final bank losses

a) Share of assets at risk among German cooperative banks

b) Final bank losses, as a share of total assets, under the 1.5 °C temperature increase

(y-axis: number of NUTS2 regions)



Sources: Orbis Bank Focus, ECB "Domestic and cross-border positions of euro area monetary financial institutions (MFIs, excluding the Eurosystem)" and JRC.
Notes: a) Share of assets at risk (NPLs) due to river flooding events in German regions among German cooperative banks compared to non-financial institutions; b) Final bank losses, as a share of TA, for the 1.5 °C temperature increase.

3.2.2 Insurance

3.2.2.1 Insurers and governments: protection gap

The European Commission's 2021 Adaptation Strategy aims to reduce the climate insurance protection gap and enhance understanding of natural disaster insurance penetration among Member States. In this context, the ECB and the European Insurance and Occupational Pensions Authority (EIOPA) (ECB-EIOPA, 2023) came up with a set of possible actions which should be considered to tackle this protection gap and mitigate catastrophe risks from climate change in the EU through insurance coverage and adaptation measures (see Section 3). Such policies are linked to the framework put forward by Bellia et. al. (2023b) to quantify the size of premiums associated with an increase in insurance penetration in the EU, while also estimating the impact on public finances when climate-related fatalities occur along with insurance sector defaults. Insurance coverage for natural disasters is typically part of fire or property insurance (EIOPA, 2022a), and the type of coverage varies from country to country (ECB-EIOPA, 2023). Due to the lack of granular data on insured natural catastrophic events, statistics on premiums for these lines of business are not available. Therefore, we rely on information on climate-related events and general statistics on the insurance sector to disentangle the share of premiums and technical provisions set aside for natural hazards.

Focusing only on coastal and river floods, potential losses from natural disasters are estimated using the risk exposure maps of the JRC Risk Data Hub. To obtain the share of insured losses related to natural disasters, we rely on the estimates of insurance penetration published in the EIOPA Dashboard on insurance protection gap for natural catastrophes. Specifically, the dashboard offers four possible buckets per country and per peril, including 0-25%, 25-50%, 50-75%, and 75-100% (EIOPA, 2022b). To further differentiate countries, values in each bucket are interpolated based on the average size of insurance coverage according to RiskMap and LitPop data.[56]

The final estimates of insurance penetration for flood events show that at least 11 countries are above the 75% threshold, [57] **while Greece and the Netherlands have a relatively low insurance penetration.** Ratios for insurance penetration are applied to the expected actual loss from flood events to estimate the potential increase in gross insurance premium written needed to reach a harmonised level of insurance penetration for flood events of 50% and 75% across EU countries (Chart 12). Actual premiums for flood events account for 12.5% of premiums for the fire and other damages to property line of business (EIOPA, 2022b), and an increase of €7.3 billion (+57%) is needed to harmonise insurance penetration for flood-related risks in Europe to at least 50%.

A stylised model is used to assess the maximum loss for public finances under a baseline case, where we consider only the one-year expected liability at the country level, and under a worst-case severe scenario, where flood events and defaults in the insurance sector materialise together. The assumptions are that no preventive action is taken to make society more resilient to climate and weather-related risks, and that there is no increase in the frequency or severity of extreme events due to climate change. At the current protection rate, expected losses stemming from flood events are estimated to be around €27 billion. This amount represents the average losses that might occur over a one-year time horizon, stemming from potential defaults of insurance companies and uninsured losses that would need to be covered by the private or public sector. The results suggest that addressing the insurance penetration rate might lead to much greater benefits, of up to an 80% reduction in losses for countries where the actual penetration rate is low (Chart 12).).[58] However, it has to be respected that countries on their own have to decide on the precise measures they want to take with regard to addressing the protection gap. In our stylised model, we are also not considering the role of re-insurers. More analysis is needed to assess whether or which physical risks are insurable as insurance relies on risks being sufficiently

---

56 RiskMap and LitPop are two data providers that collect and maintain data on insurance penetration and potential replacement costs in the event of a natural disaster. Further information on these two data providers, together with the assumptions made, can be found in the **technical description annex** of the EIOPA Dashboard on insurance protection gap for natural catastrophes.

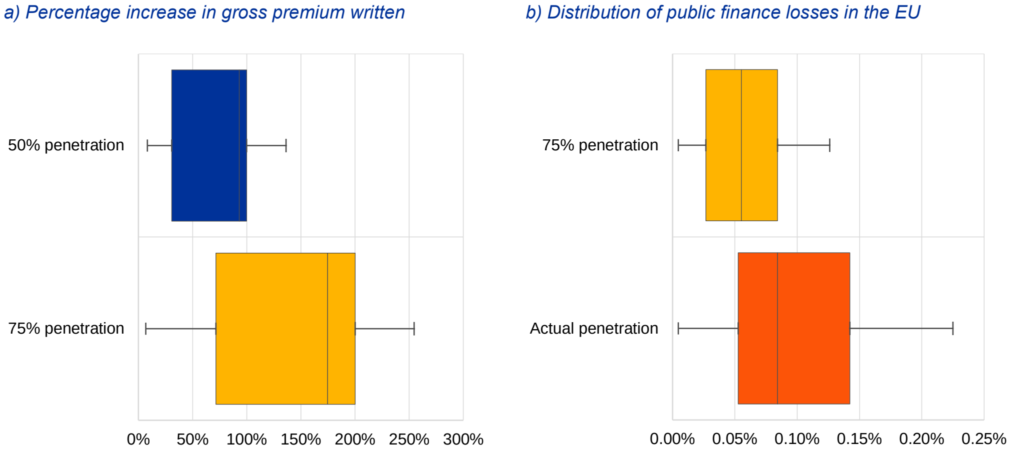
57 Member States that are above 75% are BE, CZ, DK, ES, FI, FR, HU, IE, LU, SE and SI. See Bellia et. al., 2023b and the EIOPA dashboard for further details. According to EIOPA, 2022b, insurance penetration rates includes both private and public insurance schemes.

58 We are not considering potential moral hazard issues, which might increase the claims for insures and thus reduce the benefits of a higher penetration rate. However, our analyses focus on short-term insurance policies, thus insurers might promptly reduce coverage in case no preventive measures (such as a dedicated regulation) are taken.

diversified across regions. The realisation of more chronic risks as well as correlated and more severe acute and potentially interdependent physical risks reduces the potential for risk diversification.

Chart 12

Insurance coverage (penetration) and premiums for flood-related risk



Sources: EIOPA insurance statistics, EIOPA Dashboard, JRC Risk Data Hub and JRC elaboration.
Notes: Panel a) boxplots represent the distribution, across EU Member States, of the percentage increase of gross premium written needed to harmonise insurance penetration for river and coastal flooding up to 50% (blue boxplot) and 75% (red boxplot). Member States that already reach the 50% (75%) penetration and NL and GR (outliers) are excluded from the plot. Panel b) boxplots show the distribution of public finance losses in the EU in the baseline, under the actual insurance penetration rate, and under a harmonised level of insurance penetration of 75% (% GDP, = 0.5%). Outliers are excluded from the plot.

3.2.3 Financial markets

This section starts by looking into volumes of green financing before delving into impacts of climate change on financial market pricing. The size of the green financing market is an important indicator to assess to what extent financial markets support the transition to a low-carbon economy. This section attempts to analyse both the overall green financing market as well as the growth in sovereign green bonds. Moreover, surveillance of climate risk requires an understanding of how financial markets price climate risk and green financing. With that in mind, this section investigates whether there is a “greenium” for green bonds, i.e. whether such bonds trade at a relatively higher price, and how climate risk news affects bond spreads.

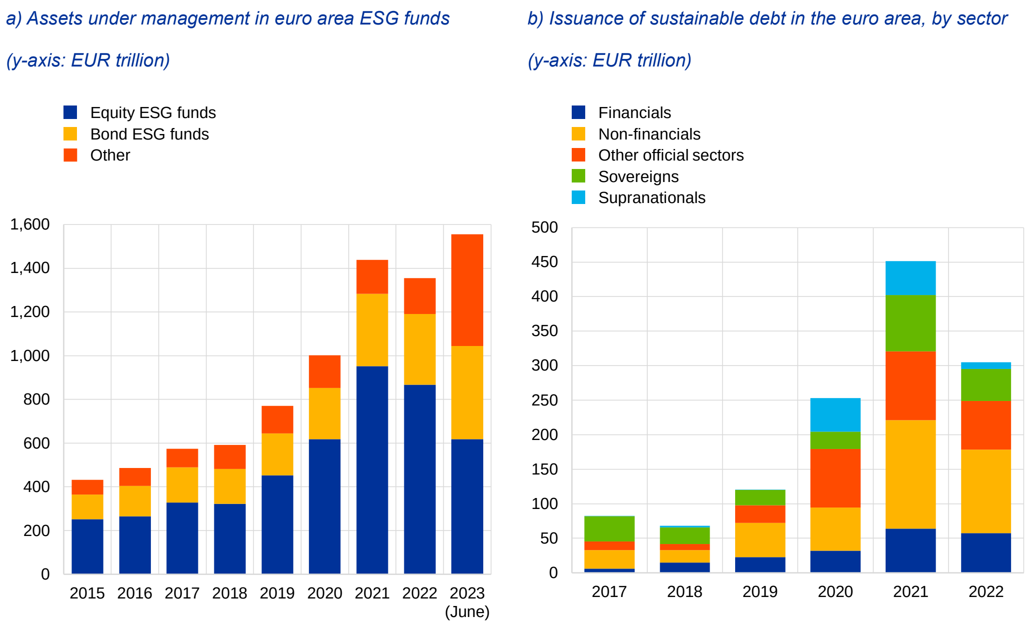
3.2.3.1 Financial market financing

Beyond the financial stability risks arising from financial exposures to climate-related hazards, green finance has been growing to support the transition to a low-carbon economy. Green and sustainable financial markets have grown rapidly (Chart 13), with outstanding amounts of sustainable debt securities issued in the euro area having more than doubled in recent years.

While holdings of sustainable debt securities have grown continuously, they still account for relatively little of the wider financial market. However, market trends reflect the anticipated green investment from the EU recovery fund and a surge in financial institutions pledging net-zero commitments. While euro area investors seem to prefer sustainable debt securities issued in the euro area, the euro area as a whole is a net buyer of these instruments – that is, its holdings outpace its issuances. Despite these advances in green financing, sustainable markets account for only 10% of the euro area investment fund sector and 3% of outstanding bonds. These limits stem partly from fragmented capital markets, and associated impediments to channelling investments towards green projects.

Chart 13

Green and sustainable financial markets have grown significantly in recent years, expanding both in terms of sectors and financial instruments



Sources: Morningstar, Bloomberg and ECB calculations.
Note: Panel a): ESG funds correspond to all sustainable funds identified using Morningstar intentions attributes based on information retrieved from fund prospectuses.

Sovereign green bond markets in the euro area continue to develop, with the proceeds directed predominantly to transport and renewable energy. Green sovereign bond issuance has increased since the pandemic, but still accounts for only a small fraction of total sovereign debt, with the proceeds mainly used for clean transport, renewables and energy efficiency (Chart 14). Governments will play a key role in reducing direct and indirect risks by fostering the transition to a low-carbon economy and investing or encouraging investment for climate change adaptation.[59] Public sector participation in green markets also often act as a catalyst, foster the growth of private sector green markets by increasing liquidity and by setting frameworks, best practices and

[59] See also Fahr et al (2023), **Climate change and sovereign risk**, ECB Financial Stability Review (May).

standards for green bond classification and verification (with an associated potential to reduce the risk of greenwashing).

Chart 14

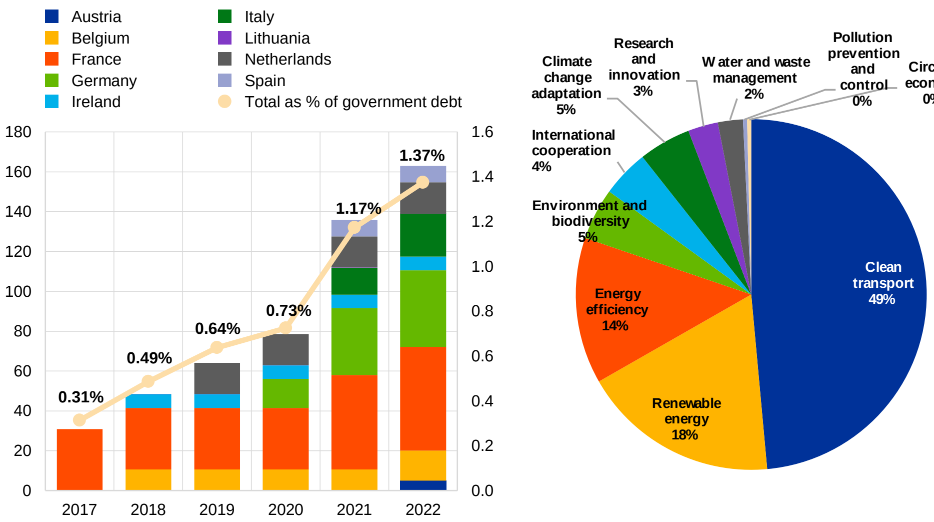
Green sovereign bond issuance over time and across sectors

a) Amount outstanding of euro area green sovereign bonds, by country

(2017-22, left-hand scale: EUR billion; right-hand scale: share of government debt)

b) Use of proceeds from euro area sovereign green bonds

(2022)



Sources: Bloomberg Finance L.P., debt agencies (allocation reports) and ECB calculations.
Notes: Panel a): the pink line represents the total amount outstanding of green bonds issued by euro area sovereigns as a share of euro area government debt. Bloomberg classifies bonds as green according to the information provided by the debt agencies. Panel b): the latest publicly available allocation reports are used.

3.2.3.2 Financial market pricing of climate risk

Early issuances of euro area green bonds benefited from the existence of a greenium. Euro area sovereigns and corporates have until recently been able to finance their green projects using green bonds at a cheaper rate than if they had issued an equivalent regular bond (with a similar maturity and the same credit risk) (Chart 15, panel b).[60] The imbalance between supply and demand in the green bond market is the most likely factor behind the existence of a greenium. In recent times, this greenium has shrunk, possibly reflecting a better supply-demand balance in a more mature market alongside growing awareness of, and concerns about greenwashing.

[60] See Ando et al (2023).

Chart 15

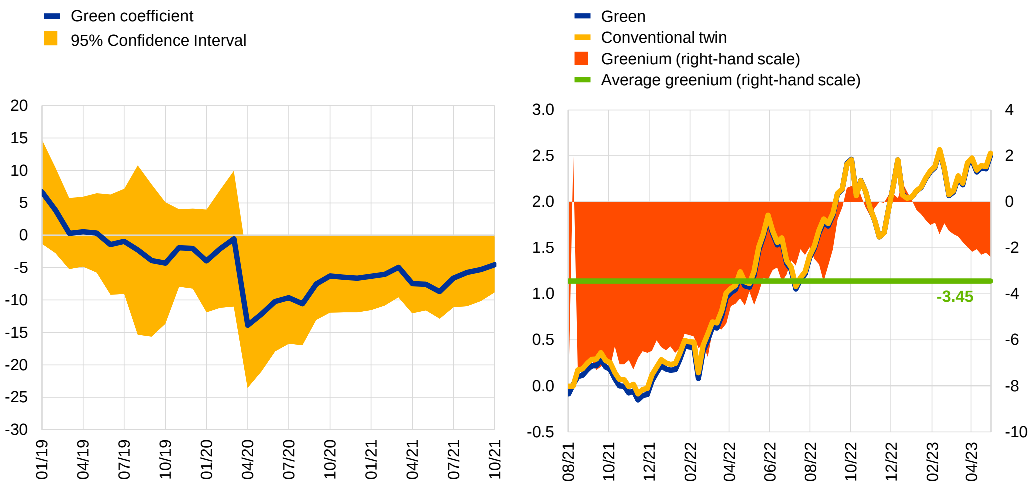
Green bond "greenium" and issuer credibility

a) Greenium of euro area corporate bonds

(difference in option-adjusted spread between green and conventional bonds, basis points)

b) Greenium of euro area sovereign green bonds

(Aug. 2021-Jan. 2023, left-hand scale: yield to maturity; right-hand scale: basis points)



Sources: Bloomberg Finance L.P., debt agencies (allocation reports) , ECB calculations and Pietsch and Salakhova..
Notes: Panel b): amount outstanding weighted average "greenium". The "greenium" refers to the difference in yield to maturity between green bonds and conventional bonds. Different methods are used in the literature to estimate this discount. For this analysis, it has been estimated by matching, when possible, each green bond with a conventional sovereign bond with similar features, such as rating and maturity (the "conventional twin").

Climate risk news and sovereign spreads[61]

As governments play a more prominent role in investing in climate and environmental action, they become major players in green capital markets. It is held that sovereigns, particularly central governments, might be issuing green bonds to signal their green credentials and commitment to finance low-carbon infrastructure, address climate change and pursue other environmental goals (Bolton et al., 2022), although it would seem that the use of green bonds does not necessarily translate into lower a cost of funding (Fatica et al., 2021).

Based on selected sovereign green bond (SGB) issuances in European countries, Bellia et al. (2023c) analyse to what extent SGB prices account for news on climate risk. The study extracts measures of volume and sentiment of climate-related daily news items from the so-called Global Database of Events, Language and Tone (GDELT)[62] and investigates how these climate news indicators affect the yields of green and similar conventional sovereign bonds on secondary markets using panel regressions.

[61] Based on Bellia et al (2023c).

[62] See https://www.gdeltproject.org/.

Chart 16

Yields of conventional and green sovereign bonds

(y-axis: yields in %)

Source: Refinitiv.
Note: Trend over time for the yields on conventional bonds (dashed black line) and green bonds (in green).

While yields on green and other sovereign bonds co-move closely over time, negative climate-related sentiments and an increase in climate-related news are associated with lower green bond yields (Chart 16). A marginal increase in the interaction variable defined by negative climate-related sentiments and news volumes leads to a corresponding decrease in green yield, whereas it does not influence the returns of similar conventional bonds. This is consistent with investor demand shifting towards green securities as climate change concerns, in the form of heavier news coverage, attract increasing levels of public attention and scrutiny. This finding is strongly driven by countries that lag further behind in climate action and are more vulnerable to climate risks.[63] This suggests that the signalling effect of GSBs is more significant for countries that need to build a strong “green” reputation and for which green bonds can be credibly used as an instrument to achieve that.

3.2.4 Systemic risk

Climate change can generate systemic risk, whereby direct climate-related events trigger cascading feedback through the economy and the financial system. The complexity and interconnectedness of the global financial and economic systems can induce climate change risk to have systemic consequences. This section explores two aspects of the systemic nature of climate risks. First, it addresses the similarity in portfolio exposures to physical risk across the financial sector. Second, it conducts an analysis into the cross-border transmission of risk across supply chains and its impact on the stability of euro area banks.

3.2.4.1 Overlapping portfolios

In addition to concentration risks, overlapping portfolios can pose a risk to financial institutions and the financial system though price correlation across groups. When physical risks in one geographic area materialise, or when risks in one economic sector are re-evaluated, the resulting losses can trigger fire sales of assets from other areas or sectors if the portfolios of financial institutions overlap – even if the portfolio appears diversified at the level of an individual institution. Overlapping portfolios between financial institutions can create contagion and ultimately systemic risk. A systemic perspective can be useful in identifying the associated risks that need to be considered in prudential regulation, as well as levels of exposure and concentration risk.

We look at global securities portfolios of financial sectors in the euro area that overlap in terms of hazard exposure. Chart 17 (panel a) illustrates risks from portfolio overlap and distinguished them from concentration risk. Assets A_i and B_j are grouped by country hazard, i.e. by their location and by hazards affecting them. Bank assets (company liabilities) are also grouped by country hazard, meaning that exposures to flood risk in France or to wildfire risk in the United States are counted together in each case.

Country hazard-related portfolio similarity across sectors has been declining in recent years and is at its highest for insurance corporations and investment funds and at its lowest for banks. The physical risk-weighted portfolio similarity index measures similarity in portfolios for different financial sectors to capture common exposures to climate-related risks (Chart 17, panel b).[64] It uses the cosine similarity index between different sectors, and then calculates the average

[63] The countries have been ranked according to the Climate Change Performance Index (CCPI), which evaluates how far countries have come in achieving the goals of the Paris Agreement. It relies on 14 indicators and the following four categories: GHG emissions (40% of the overall score), Renewable energy (20% of the overall score), Energy use (20% of the overall score), and climate policy (20% of the overall score). For more information, visit https://ccpi.org/download/climate-change-performance-index-2022-background-and-methodology.

[64] Hazard scores are taken from Moody’s. The data provide a forward-looking indication of the climate-related exposures and threats facing real estate, corporate facilities, infrastructure, and other real assets. The following six hazards are covered: floods, heat stress, hurricanes and typhoons, sea level rise, extreme water stress, and wildfires.

similarity of one sector with all the others.[65] The physical risk-weighted portfolio similarity index for investment funds has a value of 0.7 with the other four financial sectors in 2022, where a value of 0 would indicate no overlap, and a value of 1 would indicate absolute portfolio similarity.[66] The decline in the index since 2016 has been driven by one group of sectors, consisting of insurance corporations, investment funds and pension funds. Institutions in this group increased their exposure to US hazards more than banks and other institutions, while euro area banks have shifted their hazard exposure slightly from France to Germany.

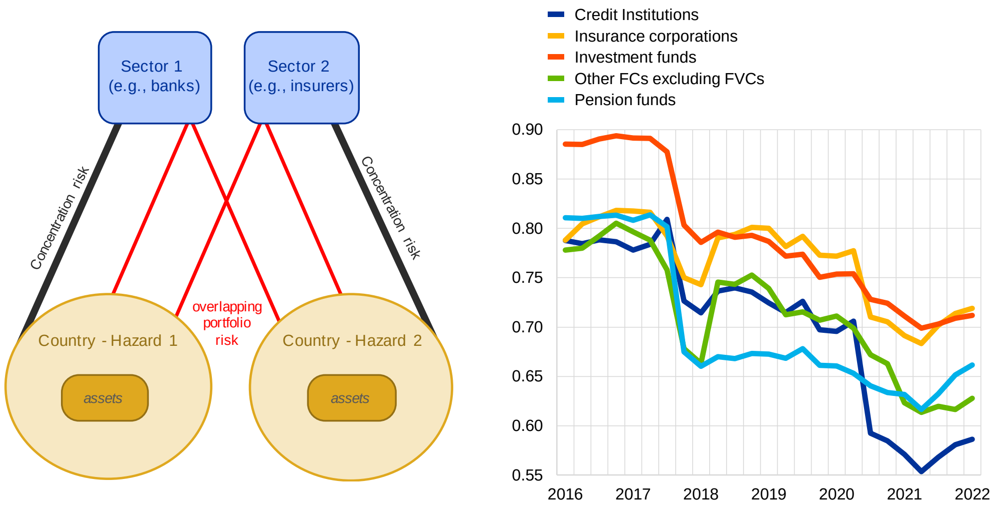
Chart 17

Overlapping portfolio risk illustrated conceptually and estimated empirically

a) Overlapping portfolio risk in comparison with concentration risk

b) Country hazard-related portfolio similarity across financial sectors

(Index; 0 = no portfolio overlap; 1 = absolute portfolio similarity)



Sources: SHSS, Moody's and own calculations.

Notes: Panel a): A1, A2 etc. represent different assets. The lines between banks and insurers as well as country hazards represent exposures. Panel b): The physical risk-weighted portfolio similarity index measures similarity in overlapping portfolios across sectors to capture joint exposures to climate-related risks. More specifically, we calculate the cosine similarity index for each sector with the other sectors and take the average to obtain an index for each sector. FCs = Financial corporations; FVCs = Financial vehicle corporations.

While there is significant overlapping portfolio risk between NBFI (non-bank financial intermediaries) sectors, the similarity between the hazard-exposed portfolios of banks and NBFI sectors is not, in itself, indicative of systemic risk. The NBFI sectors have similar hazard-weighted portfolios mainly due to relatively large common exposures to global climate issues such

65 The financial sector is split into five subsectors: credit institutions (banks), insurance corporations, investment funds, pension funds, and other financial corporations. We then calculate a hazard-weighted portfolio vector A for each subsector by multiplying ordinary exposures in SHSS with 247 scores of physical hazards per country. The cosine similarity between two sectors is then the cosine of the angle between the two hazard-weighted portfolio vectors, or equally the normalised dot product: $CS = \cos\alpha = \frac{A \cdot B}{||A||\,||B||}$.

66 The index is close to 1 one for all sectors if we differentiate only by hazard instead of hazard-country.

as US wildfire risk, representing indeed a systemic risk via fire sales/revaluations. However, banks' portfolios are less similar to those of insurance corporations, investment funds and pension funds because their exposures to such global issues are relatively contained.

3.2.4.2 Physical risk amplification through supply chain networks

In addition to common exposures, the interlinked nature of the global supply chain network can lead to the transmission and amplification of physical risk events. Ojea-Ferreiro et al. (2023) examine the impact of flood events in a network model to analyse propagation of shocks and their transmission through the global supply chain network. It uses firm-level data on the supply chain, company location and balance sheet information from FactSet, combined with global flood hazards by the JRC with grid resolution of less than one kilometre and flood return periods of 100 years.

The results indicate large heterogeneity in the impact of flood events, both in magnitude and in speed of transmission. The analysis reveals that the number of firms initially affected and their total number of customers strongly affect the speed of the transmission of flood risks, while the input criticality of firms, meaning how essential a firm's input is to its customers, determines not only the transmission of the impact but also its magnitude. For this reason, it may serve as an early warning indicator for supply chain disruption. Overall, given the localised nature of floods, granular analyses can provide useful insights on the specific mechanisms underlying the direct and indirect impacts of this kind of natural disaster on companies to provide indications of systemic risk.

Beyond individual firm linkages, an economy exposed to physical risks may experience losses that reverberate across borders and generate further GDP losses in other countries. Domestic economic disruptions may affect economic activity around the world due to input-output linkages along global value chains (GVCs). Heat stress in South Asia may, for example, reduce activity in Europe by slowing the flow of goods needed for production in Europe. Moreover, disruptions to parts of GVCs that are more difficult to substitute lead to higher contagion from the initial shock, similar to a firm's input criticality.

To assess the global transmission of physical risk, regional GDP-at-risk metrics are combined with a global input-output model at the sector level. The GDP-at-risk data of S&P Global Ratings quantify the potential direct impacts of physical risks on GDP at the country or regional level.[67] The data for the RCP8.5 scenario are used to shock in an input-output (IO) model to estimate the propagation of losses across global regions at the sector level.[68]

To investigate input-output linkages between country-sectors, conventional IO models are extended to simulate supply and demand shocks simultaneously and to account for substitution effects. The materialisation of physical risks from climate change reduces both

---

[67] The GDP-at-risk data of S&P Global Ratings are quantified by combining (i) physical risk exposure metrics for drought, wind, flood and heatwave scenarios by the year 2050 with (ii) historically-estimated physical hazard losses per exposed GDP. See "Weather Warning: Assessing Countries' Vulnerability to Economic Losses from Physical Climate Risks", S&P Global Ratings, 2022, accessible **here**. Note that any conclusions drawn from the analysis contained in this section are not attributable to S&P Global Ratings.

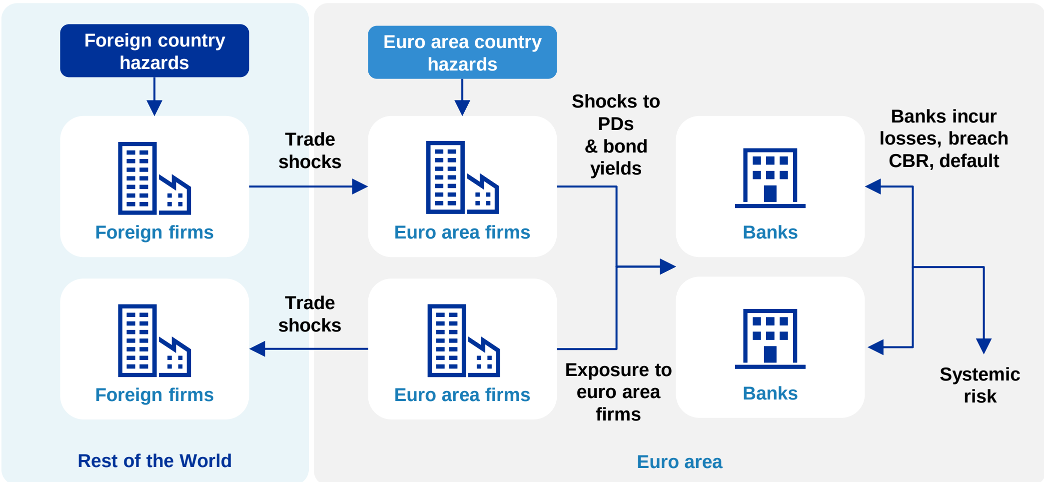
[68] The GDP-at-risk data of S&P Global Ratings are quantified using a static approach, so that second-round effects, including input-output linkages, are not taken into account, thus avoiding the risk of double-counting.

domestic final demand and production capacity. As an example, the materialisation of a climate change-related hazard in south Asia will result in lower final demand in South Asia for the output produced domestically and abroad, because of the reduction in income likely to follow the occurrence of a natural disaster. Moreover, production sites in south Asia may also be damaged or destroyed, reducing their productive capacity and also causing a supply shock. The simulation-based IO methodology implemented allows us to model the propagation of simultaneous supply and demand shocks.[69]

Trade reallocation can help mitigate the effect on economies if input sourcing can be reorganised. The capacity to reallocate trade defines how much of the missing input goods can be substituted within a global production sector. Country-sectors with firms that can reallocate their input sourcing in case of stress help to mitigate systemic risk. Moreover, if global production sectors are able to accumulate inventories, these can then be used to cope with the additional demand created when shifting supply chains. A case in point is the European automotive industry. If faced with a reduction in inputs from steel producers in south Asia, it could shift its metal demand to North America given the trade linkages, but only if the North American metal sector had built up sufficient inventories.

Figure 3

Amplification of climate-related physical risks through input-output linkages and financial contagion



Source: ECB/ESRB Project Team.
Notes: Euro area firms can suffer losses from the materialisation of both domestic hazards and climate hazards abroad because of their trade relations. Euro area banks are, in turn, exposed to euro area firms and may sustain credit losses, as well as second-round contagion losses. Note that exposures to households and financial linkages to the rest of the world are not part of this analysis.

Aggregate euro area income losses from the real economy increase credit risk for banks, with a risk of second-round losses from financial contagion (Figure 3). GDP losses induce higher probabilities of default for stressed non-financial companies, which increases the credit risk

69 Specifically, GDP-at-risk numbers from S&P Global Ratings are used to shock final demand as well as total gross output in the IO model in order to capture both supply and demand effects.

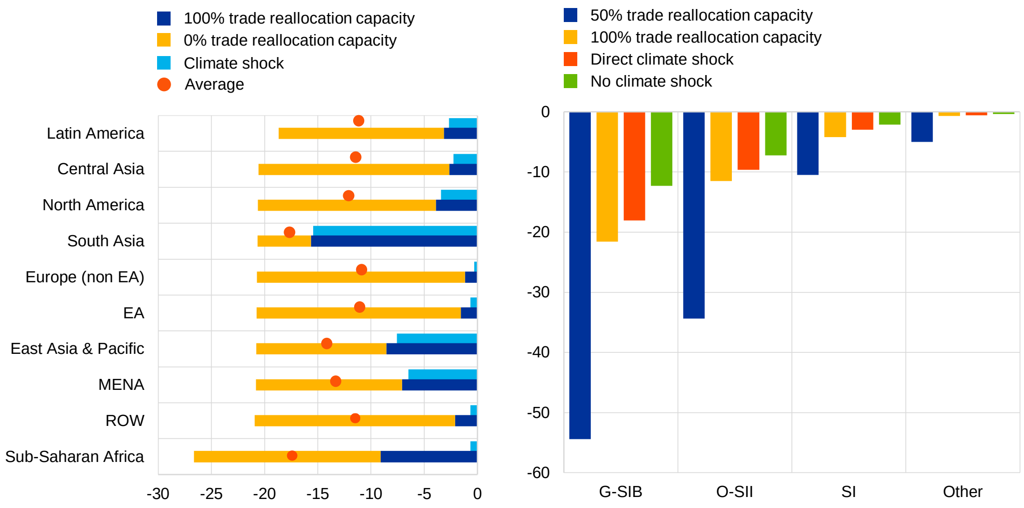
for banks. Euro area bank losses depend on their exposures and can generate contagion dynamics[70] across the banking sector in the event of fire sales due to overlapping portfolios.

Chart 18

Cross-border transmission of physical risks

a) Decline in GDP levels across world regions by 2050 due to direct physical risk and amplified through trade interconnections, in an adverse climate scenario (RCP 8.5) where all hazards materialise simultaneously (GDP decline in percentage points)

b) Average capital losses per bank type in the 9th most adverse simulation decile; in a conventional stress test scenario and in three adverse climate scenarios by 2050 where all hazards materialise simultaneously (percentage of total capital)



Sources: OECD, S&P Global Ratings, AnaCredit, SHSG, FINREP and ECB calculations.

*Notes: LHS: the amplified GDP losses through trade interconnection are simulated through an input-output model developed at the ECB. A 100% Trade Reallocation Capacity (in dark blue) implies no cost for reorganising supply chains across trading partners and 0% precludes trade reorganisation. An adverse climate scenario is considered, i.e. RCP 8.5 scenario by 2050 with no adaptation measures and where all country-specific hazards materialise simultaneously across the world. RHS: The conventional scenario (green) is based on EBA stress tests. The three adverse climate scenarios all consider an RCP 8.5 scenario by 2050 where all hazards realize simultaneously. The climate scenarios differ by (i) not taking cross-border linkages into account (red), (ii) taking them into account and allowing for maximum trade reallocation (yellow), and (iii) taking them into account and allowing for some trade reallocation. The data cover a sample of 6308 banks in the Single Supervisory Mechanism (SSM) area. The groups are the following: Global Systemic Important Banks (GSIB, eight entities), Other Systemically Important Institutions (OSII, 79 entities), Significant Institutions (37 entities), and others (1617 entities). The results for losses are modelled using a multi-layered network model (see **Financial Stability Review, May 2019**, Special Feature B for details (ECB, 2019)).*

Global input-output linkages can strongly amplify direct output losses from physical hazards. If physical hazards materialise globally, GDP in the global regions falls, with south Asia presenting the largest direct losses with a GDP decline of more than 15% (Chart 18, panel a)[71]. Countries in Central Asia, Sub-Saharan Africa, and the Middle East and north Africa experience the second largest GDP decline, whereas European countries experience an average direct climate GDP shock of up to 0.6% due to their limited exposure to extreme hazards. The GDP losses are

[70] Contagion dynamics are simulated using a multilayered network model developed at the ECB (see Belloni et al., 2022)

[71] The scenario of S&P Global Ratings quantifies GDP-at-risk in 2050 for an RCP 8.5 scenario including heat stress, water stress, floods, sea level rise, storms and wildfires.

then amplified once these initial shocks propagate through GVC linkages.[72] In Europe, GDP losses from these indirect channels are more than ten times greater on average than the losses incurred from the direct shock.[73]

A sector-level analysis reveals that the propagation of climate physical risks through GVCs has heterogeneous effects for the real economy and the banking system. On aggregate, the euro area wholesale and retail trade sectors would be hit the hardest.[74] For the banking system, higher losses for the real economy result in financial losses first through the realisation of credit risk and consequently through intra-financial system contagion dynamics. Accounting for vulnerabilities stemming from physical climate risk shows that the banking sector might find itself under significant pressure if climate change mitigation efforts are further delayed. Global Systemically Important Banks (G-SIBs) appear to be strongly exposed to the realisation and amplification of physical risks, even under the scenario where full trade reallocation were to take place.

3.3 Scenario-based vulnerability assessment

Climate-related risks can quickly become material, despite the long time horizon over which they may materialise or the high uncertainty as to the timing and scale of their impact. Previous analyses and forward-looking exercises (ECB, 2022a; ECB/ESRB, 2022; and NGFS, 2023d) show that they can already become material within the next decade, depending on how orderly the transition to net zero unfolds or how abruptly changes in expectations and innovation on clean energy technologies take place.

While most climate scenario analyses to date have been exploratory in nature, efforts are now geared towards ensuring they are able to inform supervisory and regulatory actions. A review of past exercises within the EU shows that the approaches used are becoming increasingly comprehensive and sophisticated (see Figure 4 and Annex 2.1 for more information on past exercises across jurisdictions). These exercises have varied in scope and design, with coverage ranging from firm level to sector or system level, and approaches including both bottom-up and top-down exercises. They also explored different narratives and risk drivers. To reflect the complexity of climate change impacts, these exercises have strived to address some of the key limitations that are likely to blame for the prevailing trend of understating exposure and vulnerability.[75] In particular, they have aimed to better capture second-round effects, system-wide consequences, cascading effects across real economy sectors, abrupt correction in asset prices, and so on. More recently, we have seen a clear need to consider both tail risks that might materialise over the short term as well as potential compound risks (NGFS, 2023a, 2023c). While a stress test exercise requires us to focus on low probability/high impact events, it is also important for climate scenario analysis to go beyond considering shocks in isolation.

---

72 GDP losses are fed into the IO model as a percent reduction of final demand as well as total gross output for each country-sector.

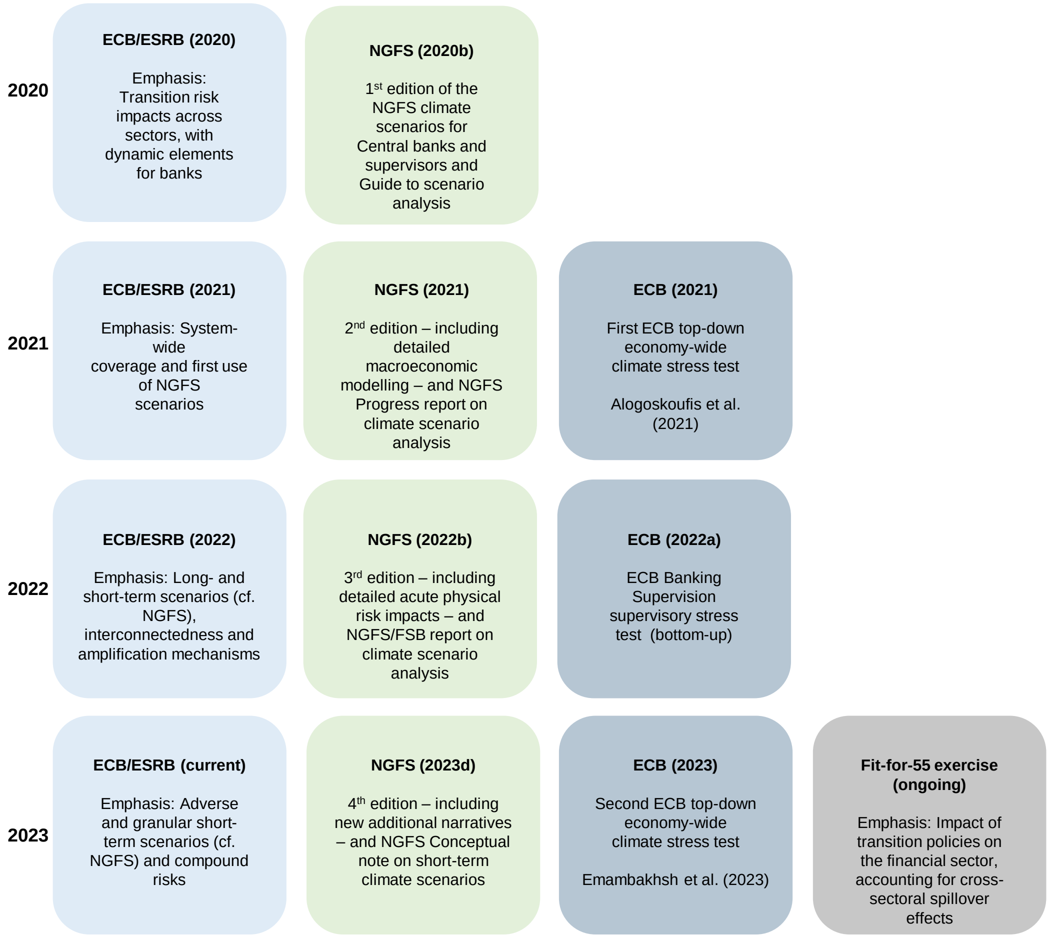
73 See Chart A7 in Annex 4.2.4.2.

74 See also Annex 1.4.2.3 for further details.

75 Many past exercises have concluded that the overall impact on financial risks would be moderate, albeit acknowledging that these should not be taken lightly and highlighting also the risk of concentration (NGFS/FSB, 2022).

Figure 4

Evolution of ECB/ESRB climate scenario analyses



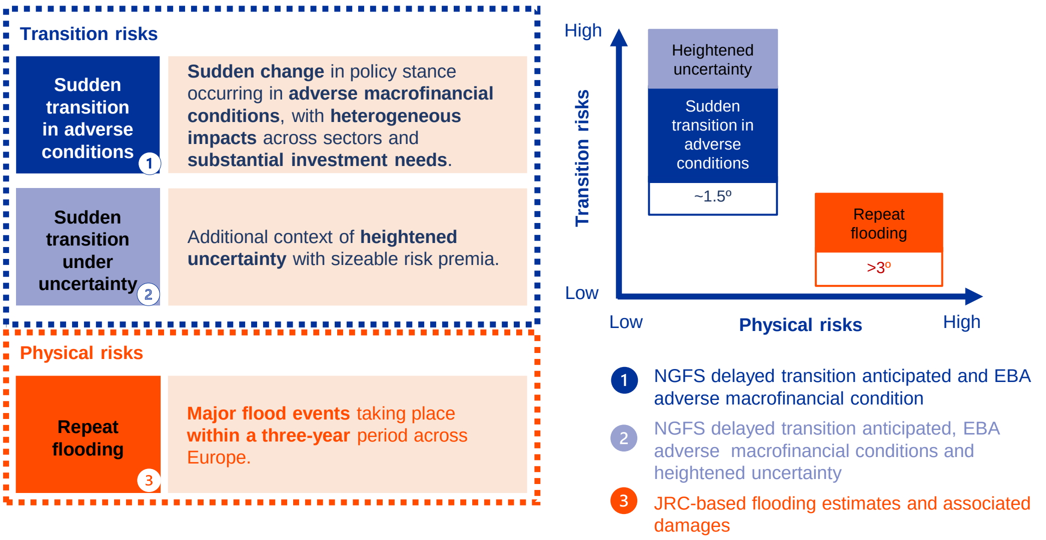
In this section, we propose three new EU-relevant short-term scenarios that account for the possible compounding of risks. We then run these scenarios to assess the vulnerability of the EU financial sector, focusing on banks and funds. This initial assessment provides some of the key parameters to calibrate macroprudential instruments.

3.3.1 Scenario design: compounding risks

This section focuses on the development of climate scenarios relevant for financial stability purposes, aiming specifically to design both short-term adverse transition scenarios and granular acute physical scenarios (Figure 5). The proposed scenarios build on the addition of a series of shocks, from a sudden transition policy shock to financial turmoil due to heightened uncertainty, while accounting for the heterogeneous impacts across sectors. In relation to physical risks, the proposed scenarios focus on flooding, which is identified as the most relevant type of physical hazard in Europe. The scenario framework assumes an increase in both the intensity and frequency of flooding events. It also accounts for the localised nature of flooding risk.

Figure 5

Scenario framework and narratives: compounding risks to design adverse short-term scenarios



Source: ECB/ESRB Project Team.

Notes: The figure shows the structure and narratives of the three adverse short-term scenarios proposed in this exercise and their expected impacts. The two transition scenarios account for the differentiated impacts across economic sectors, as well as for new investment transmission channels to firms and financial institutions. The physical risk scenario assumes that multiple flooding hazards happen in consecutive years, thus not allowing for a full recovery.

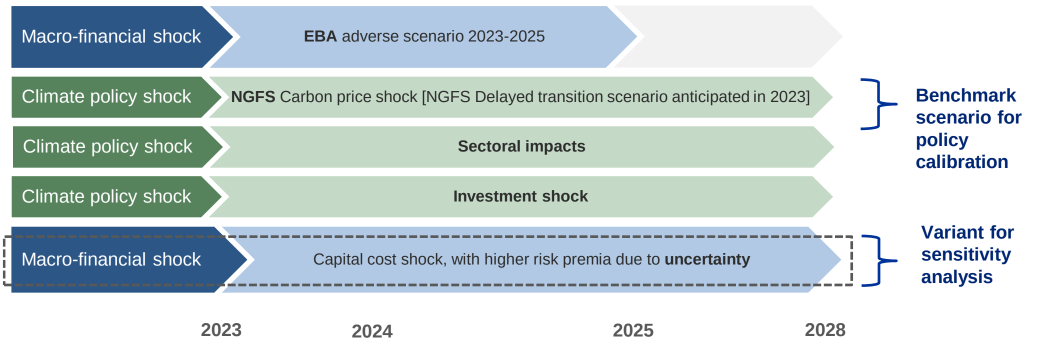
Each scenario builds on the compounding of risks, inducing additional pressure on the vulnerabilities of financial institutions and the wider financial system. The scenario framework shows that the impact of climate change might be the outcome of interrelated environmental, political and economic crises. When combined, the impacts of each risk can be multiplied in unprecedented ways. However, the full scope of these amplification effects is not fully explored in this report, thus representing an important research avenue looking forward. The impacts arising from the constructed climate shocks are presented in deviations from a baseline scenario that assumes a *status quo.*[76]

[76] This baseline comprises the EBA baseline scenario from 2022 to 2025, coupled with the NGFS "Current Policies" scenario from 2026 to 2027. It assumes that only the current policies are implemented and result in high physical impacts materialising over the medium to long term. Please note that over the five-year time horizon selected in this report (2023-27), there is no significant difference in the NGFS scenarios in terms of physical impacts.

3.3.1.1 Two transition risk scenarios

Figure 6

Two short-term adverse transition scenarios: a benchmark for policy calibration and a variant for sensitivity analysis



Source: ECB/ESRB Project Team.
Notes: The two short-term scenarios proposed include a benchmark scenario assuming that the transition happens in a context of adverse macro-financial conditions, with heterogeneous impacts across sectors and requiring massive investments from both public and private sectors, and a second variant that also factors in the impact on the financial markets of the uncertainty associated with the transition. The EBA scenarios stop in 2025. After 2025, macro-financial variables are projected forward with the NGFS Delayed transition anticipated in 2023.

Regarding transition risk, two short-term scenarios have been simulated: a benchmark scenario that can be used for stress testing purposes and a variant accounting for the impact on the financial markets of the uncertainty associated with the transition (Figure 6). The variant assumes an additional shock related to an environment of heightened uncertainty with sizeable risk premia. While the benchmark can be used for policy calibration, particularly macroprudential policy, the variant would be an interesting candidate for sensitivity analysis. Both scenarios build on a common framework providing identical variable outputs and a common set of modelling assumptions. The proposed scenarios share many similarities with two of the three narratives developed by the NGFS for its short-term scenarios (NGFS, 2023b). The new NGFS "Sudden wake-up call" scenario narrative explores how the NGFS long-term "Delayed transition" scenario could behave in the short term, and this report provides a first attempt at estimating this narrative[77]. The NGFS "Green bubble" scenario focuses on a confidence crisis and a sharp increase in risk premia, a key feature analysed in the present adverse variant.[78]

A benchmark scenario: transitioning under adverse conditions

The benchmark scenario assumes that a sudden transition is required under unfavourable macroeconomic conditions. The conjunction of repeated natural disasters, increasing pressure from civil society and global tensions driving energy markets away from climate objectives requires

[77] Note that the ECB 2022 climate risk stress test (ECB, 2022b) already built on a similar approach.

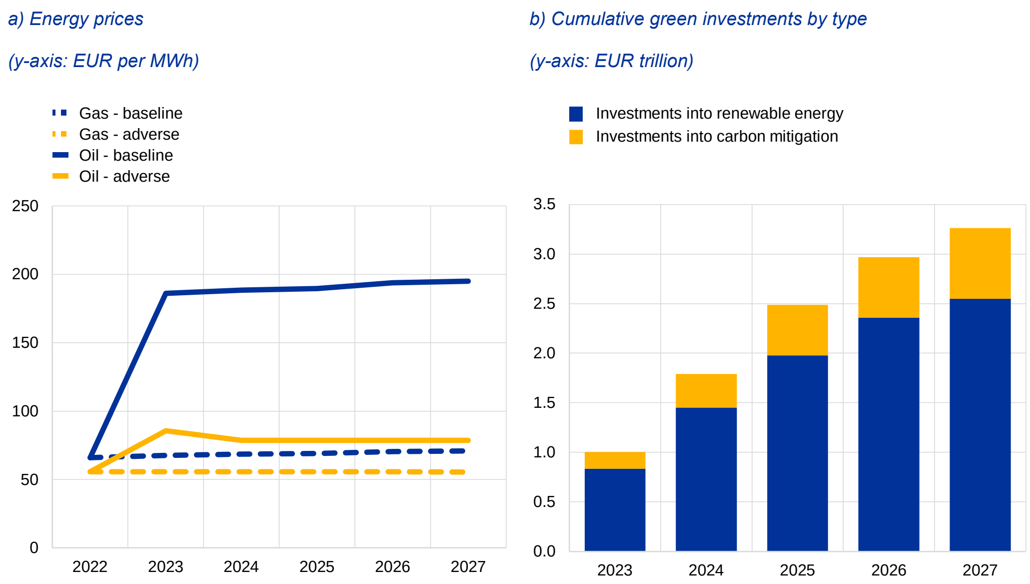
[78] The third transition narrative proposed by the NGFS in its "Highway to Paris" scenario reflects an immediate and technology-driven transition.

a sudden correction in policy stance in 2023-24 as countries depart from their committed targets. Governments need to implement stringent mitigation actions, from regulations to pricing policy levers, but in a context of adverse macro-financial conditions. The implementation of these measures has heterogeneous impacts across sectors and requires massive investments from both the public and the private sector. This scenario represents the hypothetical case of a disorderly transition due to the introduction of necessarily abrupt policy measures at an unfavourable juncture in time.

The price of carbon – a proxy for the stringency of the mitigation actions implemented[79] – increases more than 20-fold over the five-year period to capture a severe but plausible tail event.[80] Carbon-intensive goods and inputs become more expensive than cleaner goods, leading to heterogeneous effects across sectors and cascading impacts throughout the value chains. Sectors and firms respond differently, depending on their carbon intensity and ability to switch from high- to lower-carbon goods or inputs. The policy actions materialise also through increased investments, including from the private sector.

Chart 19

Energy prices and green investments in the scenario



Sources: Panel a): ECB calculations based on EBA and NGFS. Panel b): ECB calculations based on Orbis, Urgentem, Eurostat, NGFS, BMPE macroeconomic projections, IRENA and IPCC data.

79 Public decision-makers have several instruments at their disposal (regulation, emission trading market, carbon taxes, etc.). The cost of these mitigation actions all result in the attribution of an implicit price to carbon emissions, which can be interpreted as the willingness to pay for a given level of emission reduction.

80 The calibration of the scenario is based on the NGFS Delayed Transition scenario. Depending on the integrated assessment model used, the price of carbon under the Delayed Transition scenario climbs from USD 15 in 2030 when the transition shock is introduced to USD 345 in 2035 (cf. REMIND model – NGFS Phase III Climate scenarios). To focus on a shorter-term horizon, the price of carbon is frontloaded to 2023.

Notes: Panel b): around 25% of the investments are channelled into carbon mitigation activities (to replace brown with carbon-neutral assets), while the rest is allocated to renewable energy capacity.

Furthermore, the sudden transition takes place in an adverse macroeconomic environment, thus amplifying the transition-related shocks. Following the EBA adverse scenario narrative, geopolitical tensions following Russia's invasion of Ukraine are assumed to aggravate matters, leading to a retrenchment of globalisation and a disruption of global production chains.[81] EU energy markets experience a drastic price jump under the adverse benchmark scenario, before rebalancing in the medium term, although prices remain constantly high (Chart 19, panel a). Gas prices climb from €65 to €180 per MWh (+170%) and oil prices from €55 to €85 per barrel (+55%) in the first two years, the main driver of this drastic price shock being the combination of rising carbon prices and adverse macroeconomic conditions. Both gas and oil prices remain high over the entire time horizon.

Rising carbon prices and energy expenses incentivise firms to significantly increase their investments towards the transition, particularly towards renewable energy. In the first year, green investments in the EU come to around €830 billion and continuously rise until 2027, reaching levels exceeding €2.5 trillion over the entire time period analysed[82] (Chart 19, panel b). This significant increase in investment has the direct effect of making firms less financially robust, with new investments funded through additional debt. The financial implications of this are exacerbated due to the overall deterioration in supply conditions and inflation rising above target.

The transition and turmoil in energy markets in an already unfavourable economic context adversely affects economic activity compared to a "business as usual" baseline scenario. Aggregate EU GDP falls by 10%, compared to baseline, over the first two years due to the adverse macroeconomic conditions (Chart 20, panel b). It contracts by a further 1.2 percentage points because of the sudden transition, reaching -11.2 % by 2024 compared to baseline and remaining on this trajectory until the end of the horizon. Please note that selecting a time series other than the NGFS data for this scenario could have added another 4.5 percentage points. The proposed impacts from the direct transition risk shock are therefore rather conservative.

Furthermore, transition shocks affect the economy heterogeneously and the disaggregation of GDP impacts by sectors is an important value added for climate stress testing. Chart 20 (panel b) shows the results for sectoral gross value added based on the sectoral model developed by Deutsche Bundesbank (Frankovic, 2022). The model relies on input-output tables, and accounts for general equilibrium effects that would occur in the event of an increase in carbon prices, including substitution across sectors and energy sources. The impact of the transition on economic activity is particularly adverse for carbon- and energy-intensive sectors, reaching a reduction in gross value added of almost 50% in the case of the fossil fuel sector. See Annex 2.2 for a similar type of modelling exercise from Banco de España, but using a different set of scenarios.

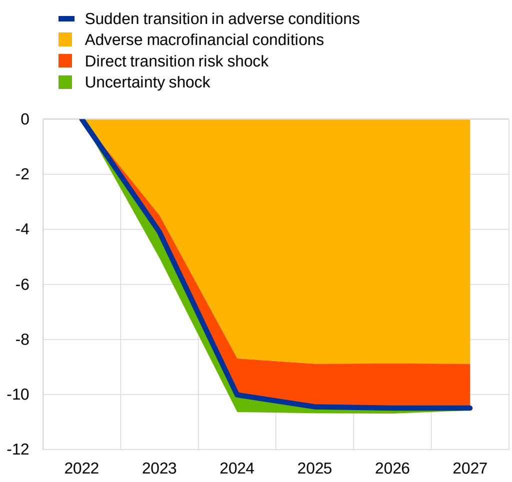
[81] The narrative and data for the projections of the overall macroeconomic environment are taken from the EBA/ESRB macro-financial scenario for the 2023 EU-wide banking sector stress test (**Macro-financial scenario for the 2023 EU-wide banking sector stress test**).

[82] Around 25% of the investments are channelled into carbon mitigation activities (to replace brown with carbon-neutral assets), while the rest is allocated to renewable energy capacity.

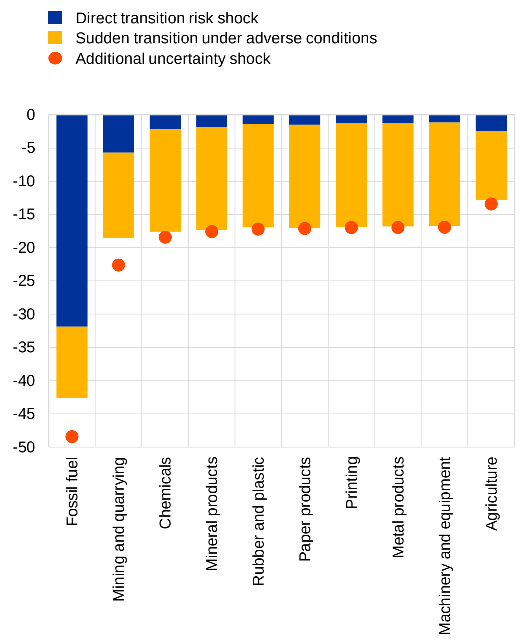
Chart 20

Impact on economic activity under the adverse transition scenarios (EU)

a) Aggregate GDP (percentage, compared to baseline)



b) Sectoral gross value added (2027) (percentage, compared to baseline)



An even more adverse variant: the cost of uncertainty

Building on the notion of interrelated shocks, the level of adversity is further heightened through a scenario variant in which an uncertainty shock related to climate transition policies is added to the sudden transition scenario. Investments in capital-intensive energy infrastructure require a high degree of certainty for planning purposes (Bernanke, 1983; Dixit and Pindyck, 1994). Using firm-level data for 12 OECD countries, Berestycki et al. (2022) find that Climate Policy Uncertainty is associated with lower levels of investment, particularly in pollution-intensive sectors. It is thus assumed in the proposed scenario that corporate costs of funding are subject to an increase in risk premia of 100 basis points for four years, before gradually falling over the rest of the scenario horizon. Uncertainty affects all sources of financing (bank, bonds and equity). Consequently, EU equity prices fall by 15% immediately and remain around 5% below their pre-shock level for five years. The magnitude of this shock on risk premia is comparable to that observed during the 2008-2009 financial crisis (Berg, 2010), though with greater persistence to reflect a more lasting impact on agents' confidence during the transition phase to a low-carbon economy. On the household side, a confidence shock calibrated based on Dees (2017) is included to account for the impacts of uncertainty on household consumption.

The macroeconomic impacts of the additional uncertainty shock are modelled using the NiGEM model[83], allowing us to embody a full macroeconomic closure of the simulation. Each country/region is modelled by a set of dynamic equations where agents are assumed to have rational expectations and where there are nominal rigidities that slow down the process of adjusting to external shocks (see Hantzsche et al. (2018) for a detailed introduction).

Chart 21

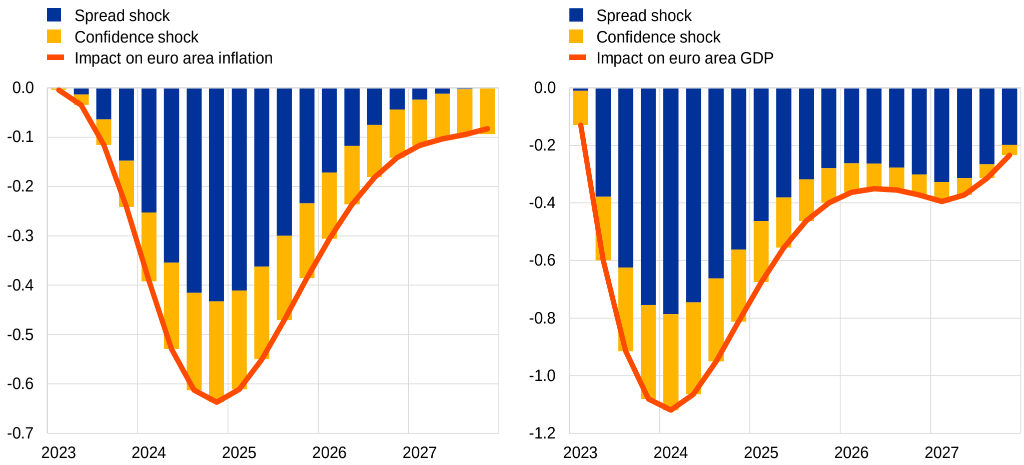
Impact of uncertainty on inflation and GDP in the euro area in deviation from baseline

a) Additional impact of uncertainty scenario on inflation

(deviation in percentage points)

b) Additional impact of uncertainty scenario on GDP

(deviation from baseline in %)



Source: Banque de France's calculations developed in Allen et al. (2023).
Note: The baseline scenario matches the NGFS Current Policies scenario.

The uncertainty shock translates into further reductions in spreads and household confidence, leading to higher volatility in inflation and growth. Euro area GDP contracts by an additional 1.1% after five quarters (Chart 21). Uncertainty contributes to falling inflation, from a high of -0.6 percentage points in absolute terms after two years. The longer the uncertainty over the transition policy, the longer the downward pressures on prices and GDP would last. After five years, the impacts slow, with a gradual stabilisation in inflation (-0.1 pp) and in GDP (-0.2 pp) compared to a trajectory without a transition. This additional shock illustrates that uncertainty about transition policies could increase levels of volatility in relation to inflation and economic growth.[84]

[83] NiGEM (National Institute Global Econometric Model) is a global macroeconomic model with a neo-Keynesian structure. Although NiGEM is not a climate model, extensions have been added to simulate macroeconomic scenarios analysing the effects of the climate transition, mainly associated with public policy action (e.g. carbon tax or border tax adjustments).

[84] Other output variables for this policy uncertainty scenario are consumption deflator, nominal GDP, household personal income, equity prices, short-term interest rates (central bank target rate), and long-term interest rates (10 years).

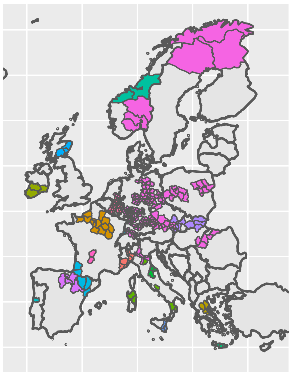
3.3.1.2 Physical risk scenarios

Flooding has historically been the most relevant type of physical risk in Europe.[85] As climate change will lead to more extreme levels of precipitation, the risk of flooding will further intensify. This may translate into losses on the exposures of financial institutions resulting from damage caused to physical assets. Scenario analysis is a useful tool for gauging the vulnerabilities of the EU financial system to flood risk.

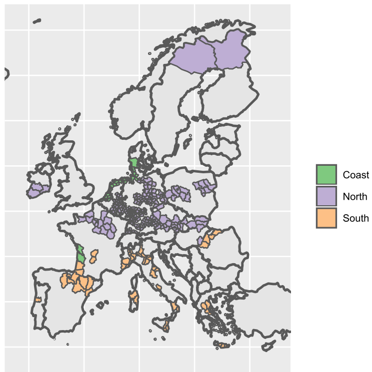
Chart 22

Past river flooding events and projected impacts by scenario

a) NUTS3 regions affected by major historical river flooding events



b) NUTS3 regions affected by the flooding scenario



Sources: Deutsche Bundesbank calculations, data from the EU European Flood Awareness System (EFAS) and Copernicus. Deutsche Bundesbank calculations, data from the EU EFAS and Copernicus for river floods. Regions affected by the coastal flood event are manually identified based on publicly available information on historical events.
Note: Each colour denotes a historical flood event.Three flood events are considered in the physical risk scenario: 1) a major coastal flood event affecting regions adjoining the Atlantic, 2) a river flood event affecting central and northern Europe, and 3) a river flood event affecting Southern Europe.

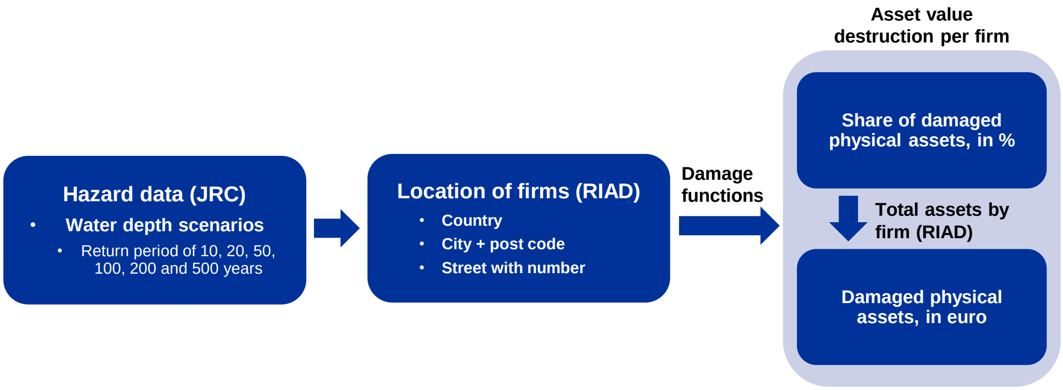
Acute natural hazards are local phenomena, and therefore spatially-disaggregated scenarios are needed for physical risk stress testing. For flooding risk, granular data on geographical vulnerabilities and affected areas of past events are available, and can help determine the geographical spread of extreme events. Granular geolocalised data on historic river flood events show the distribution of affected regions across Europe (Chart 22, panel a). Based on the flood regions identified, a scenario can be constructed whereby three major flood events take place within a three-year period (Chart 22, panel b). In year one, severe windstorms in the Atlantic lead to coastal flooding in regions adjoining the Atlantic, affecting the Netherlands, Belgium, Germany and France (see “Coast” in panel b above). In year two, massive rainfall in central and northern Europe and exceptional amounts of smelting snow in Finnish and Swedish Lapland results in river flooding in several regions across Germany, France, Sweden, Finland, Austria, Poland, Czech Republic, Hungary, Slovakia and Ireland (see “North” in panel b above). Finally, in year three, another major

[85] See Steinhausen et al. (2022).

river flood event takes place in Southern Europe, affecting regions in Portugal, Spain, France, Italy, Romania and Greece (see "South" in panel b above).

Figure 7

Data and modelling of firm-level losses from flooding scenarios



Source: ECB/ESRB Project Team.

Stress testing frameworks need to account for the spatial granularity of flood events when quantifying potential losses among corporate borrowers. Within affected regions, economic damage may vary substantially, depending on the exact location of a firm's physical assets, requiring estimates of firm-specific damage to physical assets to adequately capture risks.[86] The impact of the flooding risk scenario on individual firms is modelled by combining three different data sources (Figure 7).[87] Granular data on area-specific water depth conditional on a flooding event is retrieved from the European Commission Joint Research Centre (JRC)[88]. Hazard data are linked to information on the addresses of European firms (country, city, post code, street name and number) retrieved from the Register of Institutions and Affiliates Database (RIAD).[89] Lastly, to calculate the damage cost of a single firm at a specific location, damage functions[90] are used to translate the intensity of flooding (in terms of water depth) into the damage caused to physical assets located in the vicinity. Data on firms' assets (sourced also from RIAD) are then used to infer damages per firm in as an absolute euro value.

Aggregating the firm-level damages sustained under the combined scenarios to NUTS3 region level reveals large differences in damage intensities across Europe (Chart 23). The

86 Geographic and geological features such as distance to river, altitude and surface influence the vulnerability of specific locations. For example, moving assets 100 metres closer or further away from a river can materially alter the intensity of the flooding and therefore the damage caused to those assets.

87 See the report titled ***Towards climate-related statistical indicators***, Statistics Committee of the European System of Central Banks, January 2023.

88 Data is geospatial format (high-resolution map of 100 x 100 m) for Europe for return periods of 10, 20, 50, 100, 200 and 500 years. To reflect that stress tests are meant to simulate the effects of adverse events, water depths in 500 year frequencies are used as an input when building the scenario. At the same time, climate change may increase the frequency of tail events, such that once rare events may become more common in the future.

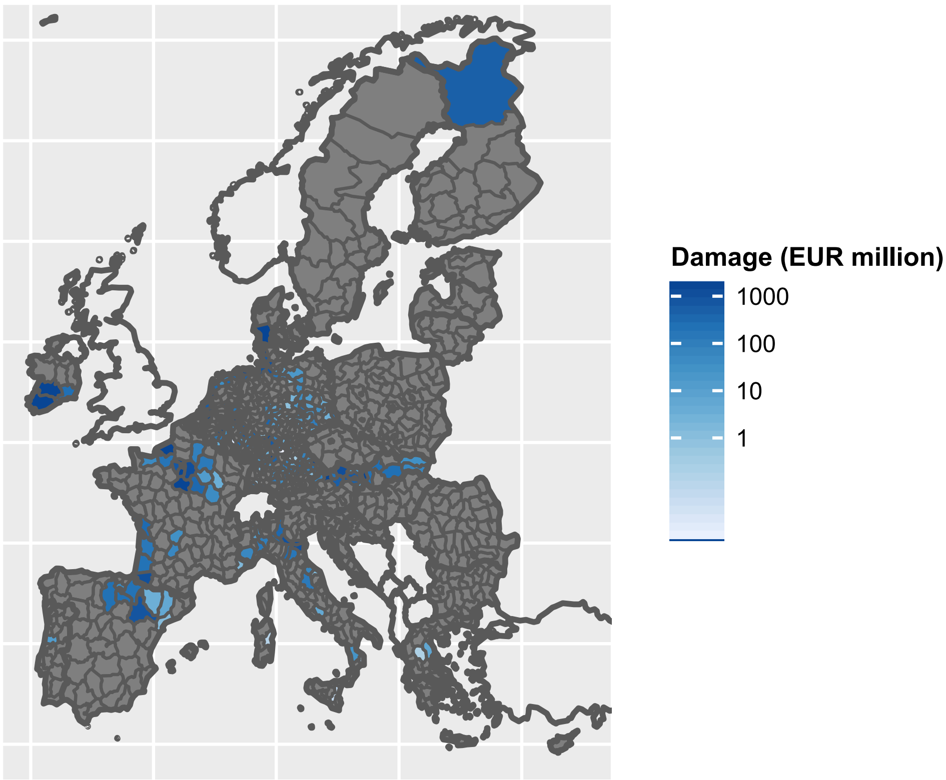
89 RIAD reports only the location of the headquarters and one branch per country. Consequently, there may be assets that are not taken into account if they belong to branches of a firm.

90 Retrieved from Huizinga, J., de Moel, H. and Szewczyk, W. (2017), "Global flood depth-damage functions: Methodology and the database with guidelines".

extent of regional damage conditional on a flood risk event depends on two main factors: 1) hazard intensity and spread, and 2) the number and size of firms in the affected area. Overall damage in a flood-affected region may therefore be limited if firms are located predominantly outside the affected area. For example, in Germany many regions are affected by the flood scenarios, yet for many of them the damage caused to individual firms is fairly mild, because it is concentrated among relatively few firms (light blue coloured regions shown below in Chart 23).

Chart 23

Damage under the flood risk scenario aggregated at NUTS3 region-level



Source: Deutsche Bundesbank calculations based on data from the Statistical Committee Expert Group on climate change indicators and RIAD.
Note: The chart shows accumulated losses (in million €) of the three flood events aggregated at NUTS3 regional level.

Damage functions are essential when calculating losses from flood risk events and their methodological constraints need to be considered when interpreting results. Damage functions assume that damage begins when the water reaches a depth of 0.25 metres, then increasing in incremental steps of 0.25 metres (see also Oliver and Sontory, 2000). Similar damage curves have been used to assess damage in various asset categories, such as commercial, industrial or agriculture. Due to their methodological constraints, findings based on damage functions should be viewed as approximations of the damage that would actually occur in the event of flooding. Damage functions are subject to various types of uncertainty, including the kinds of material used and the types of building affected by the event. To get around this problem, it would be necessary to create a damage function for each type of building and each home or business affected, which is impractical. Modelling uncertainty can also relate to the use of flood depth as a single indicator of hazard intensity. This indicator may be subject to imprecise measurement, uncertain model output or confidence levels estimated from extreme value statistics.

3.3.2 Vulnerability assessment

This section aims to assess potential vulnerabilities in the EU financial sector under the scenarios proposed above. To safeguard financial stability and to assess the capacity of the financial system to support the transition to net zero, central banks and supervisors need to monitor the resilience of the financial system under stress conditions.

3.3.2.1 Transition risk

The results show that the combination of a sudden transition with adverse macroeconomic conditions leads to a significant rise in credit and market risk for both banks and investment funds. Risk is predominantly driven by losses in energy-intensive sectors, which are more exposed to transition risks. This section first presents the results for banks and then for funds.

Financial losses – Banks

The ECB top-down, economy-wide climate stress test model is used to estimate the impact of the sudden transition scenario on firms in the real economy and the risk transmission to the corporate loan books of banks. Using granular firm-level information on corporates' balance sheets and their vulnerability to transition risk, the first step involves capturing the transmission of various transition risk drivers on firms' balance sheets under each of the scenarios considered. The resulting changes in profitability and leverage among firms due to transition risk are then used to estimate the change in their respective probabilities of default (PD) over time. As a final step, the firm-level PD shocks are translated into corporate loan portfolio PD shocks using granular information on banks' individual loan exposures towards firms. Detailed information on the methodology and data used can be found in the report on the second ECB top-down climate stress test.[91]

The overall impact of the sudden transition scenario on credit risk relative to the baseline can be further decomposed into impacts from a direct transition risk shock and an adverse macroeconomic shock. The latter is obtained by taking the difference in credit risk under the Current Policies scenario once under baseline and once under adverse macroeconomic conditions. The impact of transition risk alone is obtained by taking the difference in credit risk between the transition scenario and the baseline (Current Policies) scenario under baseline macroeconomic

---

91 T. Emambakhsh, M. Fuchs, S. Kördel, C. Kouratzoglou, C. Lelli, R. Pizzeghello, C. Salleo and M. Spaggiari (2023), "**The Road to Paris: stress testing the transition towards a net-zero economy**".

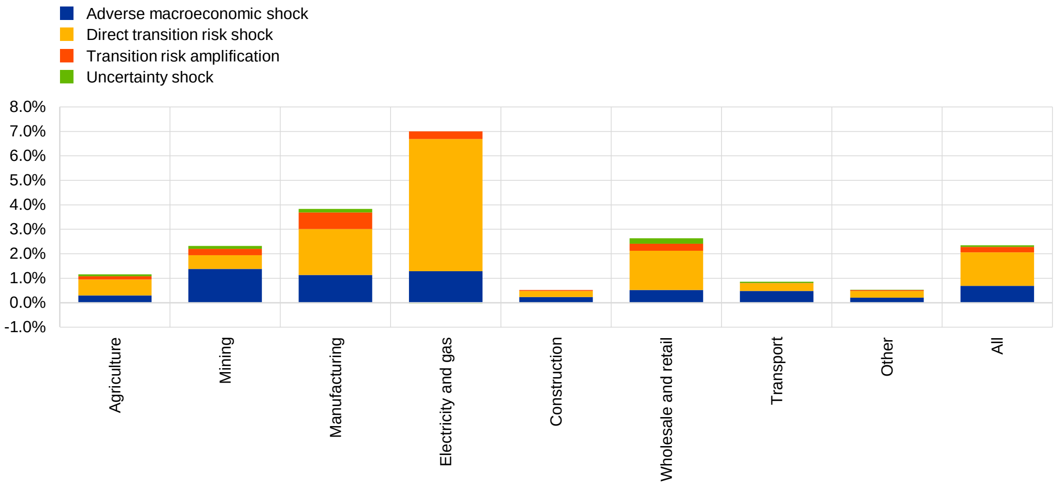
conditions. Ultimately, the amplification of transition risk is defined as the difference in credit risk between the overall compounding effect and the impact of transition risk alone.

A sudden green transition leads to a rise in sector-level credit risk, particularly in energy-intensive sectors. Average firm-level PD would rise by 0.7 percentage points (ppts) from 2022 to 2027 due to adverse macroeconomic conditions alone. Transition risk alone would lead to an increase in PD of around 1.4 ppts and would be further amplified by an additional 0.2 percentage point increase due to adverse macroeconomic conditions (Chart 24). Overall, the compounding effect of adverse macro shocks and transition risk would lead to a total PD increase of around 2.3 ppts in a sudden transition scenario. The uncertainty shock would increase average firm-level PD by an additional 0.07 percentage points.

Chart 24

Impact of transition risk on sector-level credit risk damage in the flood risk scenario aggregated at NUTS3 region-level

Increase in average probabilities of default by sector between 2022 and 2027, relative to baseline scenario

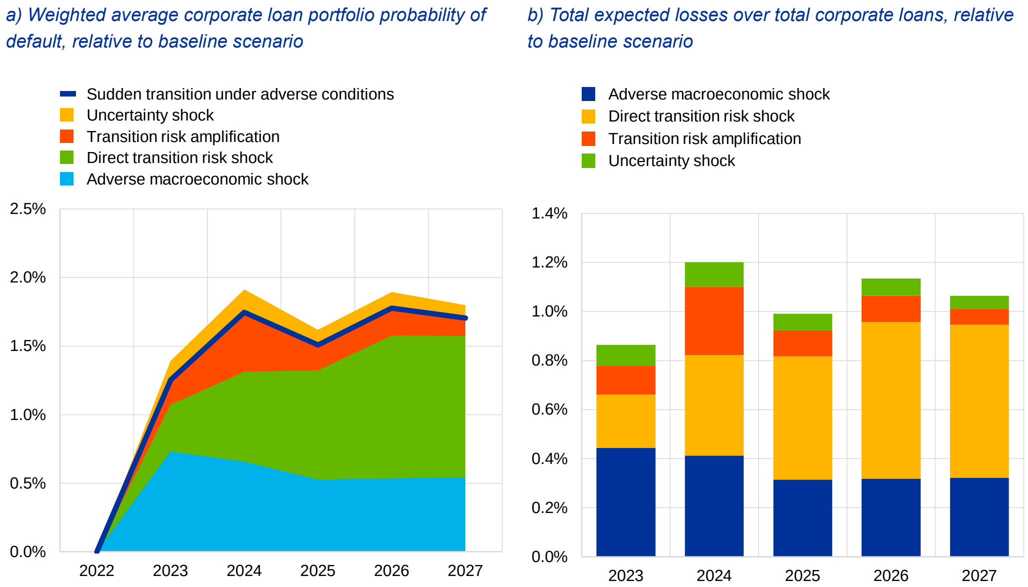


Source: ECB calculations based on Orbis, Urgentem, Eurostat, NGFS, BMPE macroeconomic projections, IRENA, IPCC and Deutsche Bundesbank data.
Note: Sector-level results weighted by amount of corporate loan exposures of each sector in euro area bank portfolios.

Energy-intensive sectors are the most severely affected under a sudden transition scenario, with electricity and gas, manufacturing, wholesale, and mining being the hardest hit. PD increases in these sectors are higher because they are energy-intensive and because substantial green investment into carbon mitigation and renewable-based electricity capacity is needed for the green transition. Electricity and gas firms would experience a total increase in PD of more than 7 percentage points until 2027, of which 5 percentage points would be incurred due to transition risk. The sector with the largest amplification of transition risk would be manufacturing, where PD would increase by 1.9 percentage points due to transition risk under baseline macro conditions alone and by an additional 0.7 percentage points due to the amplification of transition risk under adverse macro conditions. A recent study at Banca d'Italia[92] estimates firm-level PD using its in-house credit assessment system and by computing the impact of changes in energy expenditure originating from different levels of a carbon tax on Italian firms' credit risk.[93] The results show that the three different carbon tax levels simulated (€40, €90 and €140 per tonne of CO_2) would increase average PD by 0.6, 2.3 and 4.1 basis points, respectively. The effect is slightly larger for the agriculture and service sectors, while there is no clear pattern relating to firm size.

Chart 25

Impact of transition risk on total banking system credit risk



Source: ECB calculations based on Orbis, Urgentem, Eurostat, NGFS, BMPE macroeconomic projections, IRENA, IPCC and Deutsche Bundesbank data.
Note: Panel a) shows the average corporate loan portfolio probability of default, weighted by the portfolio size of banks.

A sudden transition scenario leads to a steady increase in credit risk for the corporate loan portfolios of the banking sector. Between one half and two thirds of additional credit risk is attributable to transition risk alone. The average corporate loan portfolio PD rises by slightly more than 1.7 percentage points (ppts) from 2022 until 2027 due to a sudden transition and by an additional 0.1 ppts to 0.2 ppts due to uncertainty shocks (Chart 25, panel a). Expected losses on outstanding corporate loans are around 0.8 ppts higher in 2023 under a sudden transition scenario compared to the baseline scenario and an additional 0.1 ppts increase in expected losses is due to

[92] Di Virgilio S., Faiella I., Mistretta A. and Narizzano S. (2023), "**Assessing credit risk sensitivity to climate and energy shocks**".

[93] Several studies carried out by Banca d'Italia assess the impact of transition risks via carbon taxes on the financial vulnerability of Italian households and firms. A first study simulates the increase in the number of vulnerable households and firms and the debt at risk associated with a sudden increase in the price of carbon, above and beyond the level already envisaged by the European Union Emissions Trading System (EU ETS). The increase is then passed to household income and to the EBITDA of firms. The results show significant heterogeneity in the expected effects. Using a counterfactual exercise and with 2018 as the base year, it is estimated that the impact on households would have been largely limited even with significant changes in prices (€200 and €800 per tonne of CO_2). However, the impact would have been considerable for micro and small firms and for companies in the agricultural, manufacturing and real estate sectors.

uncertainty shocks (Chart 25, panel b). Transition risk makes up around half of the increase in PD and expected losses in the first years but thereafter has more of an impact than non-transition-related macro shocks until 2027, by which time it accounts for around two thirds of the total impact. The amplification of transition risk is at its strongest at the start of the transition, but gradually fades as the economy recovers from the initial adverse macro shocks.

The German banking sector presents similar results under the sudden transition scenario and the uncertainty variant, according to an alternative stress test model framework proposed by Deutsche Bundesbank (Annex 2.2.3).[94] Substantially similar results were also estimated in a study conducted by Banca d'Italia.[95] The authors estimated the default rates (sectoral) of loans to firms from Italian banks based on the share of financially vulnerable firms and their debt. The results shows that, if every tonne of CO2 emitted had been penalised with a carbon price of €50 in 2018, the average quarterly default rate for loans to firms would have increased by about one fourth in the following year (from 2.8% to 3.6%), though still remaining below the historical average observed in the years 2006-2019. The estimates obtained reflect the relatively strong financial structure of firms and the low default rates recorded in 2018. The effect would have been greater and more varied across sectors with a tax of €800. Introducing carbon pricing in periods of greater vulnerability for firms or with higher default rates could therefore have a more significant impact.

Financial losses/risk parameters – Funds

The European Securities and Markets Authority (ESMA) has estimated the impact of the proposed sudden transition scenario on the portfolios of around 19,000 European investment funds with €10 trillion in assets under management.[96] The current model focuses on funds' direct and indirect exposures to equities[97], which account for slightly more than half of total assets under management in the sample of funds.

For the first time, the fund simulation features a dynamic adjustment of fund portfolios in response to market shocks. This dynamic modelling is set out and discussed in detail in ESMA (2023c). The model implements a sequential adjustment of portfolio values within a given time period (in this case one year), involving the following steps:

1. Incoming market shocks cause direct and indirect losses in a fund's portfolio positions.

2. Fund investors react according to a fund's overall performance, withdrawing capital from funds with losses following the shock in proportion to the magnitude of the loss. In contrast, investors

---

94 See Frankovic, I., Etzel, T., Falter, A., Gross, C., Ohls, J., Strobel, L. and Wilke, H. (2023), "Climate transition risk stress test for the German financial system" *Bundesbank Technical Paper 04/2023*.

95 See Aiello, M.A. and Angelico, C., "Climate change and credit risk: The effect of carbon taxes on Italian banks' business loan default rates", Banca d'Italia, *Journal of Policy Modeling*, 2023, also published as Banca d'Italia, *Questioni di Economia e Finanza (Occasional Papers)*, 688, 2022.

96 The dataset of European investment funds was obtained from Morningstar and reflects portfolio values as of end June 2023. Around 16,000 funds in the sample are undertakings for collective investment in transferable securities (UCITS), with the remainder being alternative investment funds (AIFs).

97 Direct exposures are defined as directly holding relevant assets, while indirect exposures are defined as holding shares in funds that hold relevant assets.

inject further capital into funds that make gains following the shock. Each fund proportionally reduces or increases all its portfolio positions accordingly.

3. As a function of fund performance and reactions among investor, fund managers decide to rebalance a certain percentage of their portfolios. For a given fund, the manager liquidates the worst performing assets and uses those proceeds to purchase the best-performing assets that are available within the fund's investment universe. Subsequently each fund manager performs a capital reallocation among all assets that they now hold from worst to best performer.[98]

Chart 26

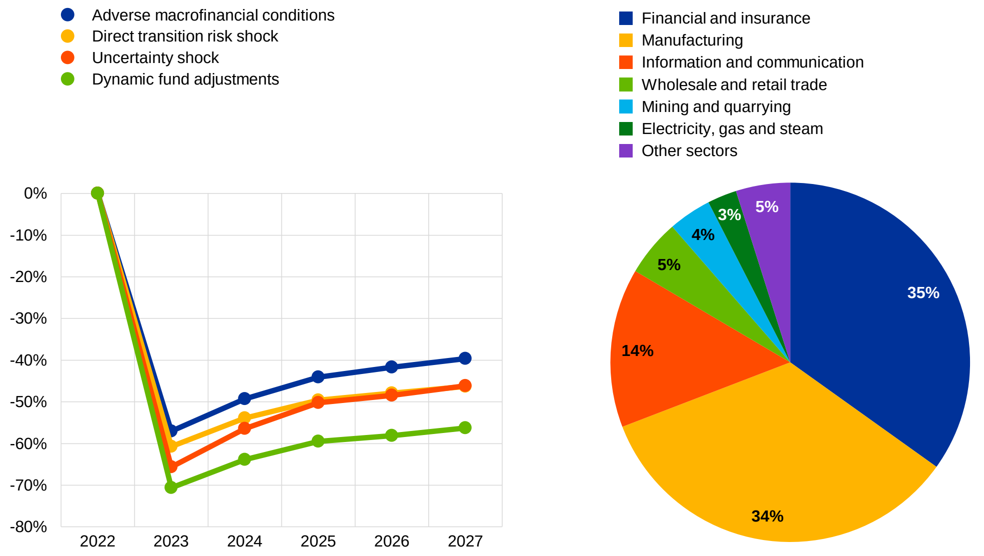
Scenario impacts on European investment funds and sectoral loss contributions

a) Scenario impacts on value of equity holdings of European investment funds

(y-axis: percentage)

b) Loss contributions of NACE level 1 sectors to system losses under the adverse scenario

(percentage share)



Sources: EBA, NGFS, Deutsche Bundesbank, Banque de France and ESMA.
Notes: The simulation focuses on funds' direct and indirect exposures to equities. Panel a): Scenario impacts on assets under management of European funds (in %). Panel b): Loss contributions of NACE level 1 sectors to total system losses under the adverse scenario (in %).

The simulation shows that under the adverse scenario[99], European investment funds may face reductions of up to 70% of the total value of equity holdings from the shock applied in 2023, with losses attenuating in later years following dynamic adjustments (Chart 26, panel a). Around four-fifths of these losses (equivalent to a 57% reduction in assets under management) are driven by the macro-financial component of the adverse scenario. In terms of sectoral contributions, equities from only three sectors (financial and insurance; manufacturing; and

[98] For a detailed description of this step and of the dynamic adjustment mechanism more broadly, including its calibration, please refer to ESMA (2023c).

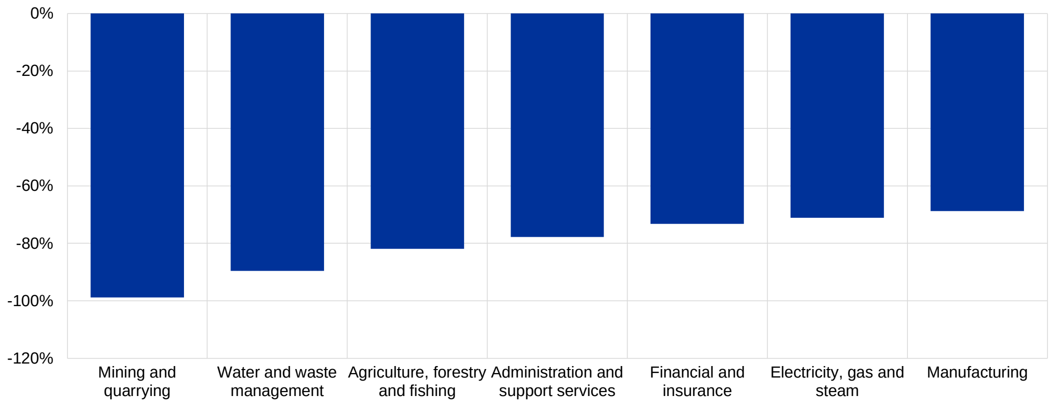
[99] Defined as a combination of adverse macro-financial conditions, a direct transition risk shock and an uncertainty shock.

information and communication) account for over 80% of total system losses (Chart 26, panel b). However, this does not mean that those sectors were the most adversely affected, as it largely reflects their dominance in equity markets. In fact, when analysing losses among the most adversely affected sectors (Chart 27, panel b), other economic activities such as mining and quarrying, or water and waste management, fare significantly worse under the assumed adverse scenario.

The current modelling of fund portfolio adjustments in combination with the adverse scenario leads to an overall shock amplification. This potentially counterintuitive result occurs because under the adverse scenario, the macro-financial, transition and uncertainty shock materialise at a single point in time, i.e. the first scenario period, with no shocks to the same assets occurring thereafter. Consequently, the dynamic adjustment of investment fund portfolios is dominated by investor redemptions in the first period (amplifying the initial shock), while the portfolio rebalancing that takes place only after the initial shock has struck cannot achieve the desired mitigating effect due to the lack of further adverse impacts throughout the years 2023 to 2027.

Chart 27

Sector losses under the adverse scenario



Sources: EBA, NGFS, Deutsche Bundesbank, Banque de France and ESMA.
Note: Loss impacts on equity holdings per NACE level 1 sector under the adverse scenario.

Box 2
Exposure of pension providers to transition risks

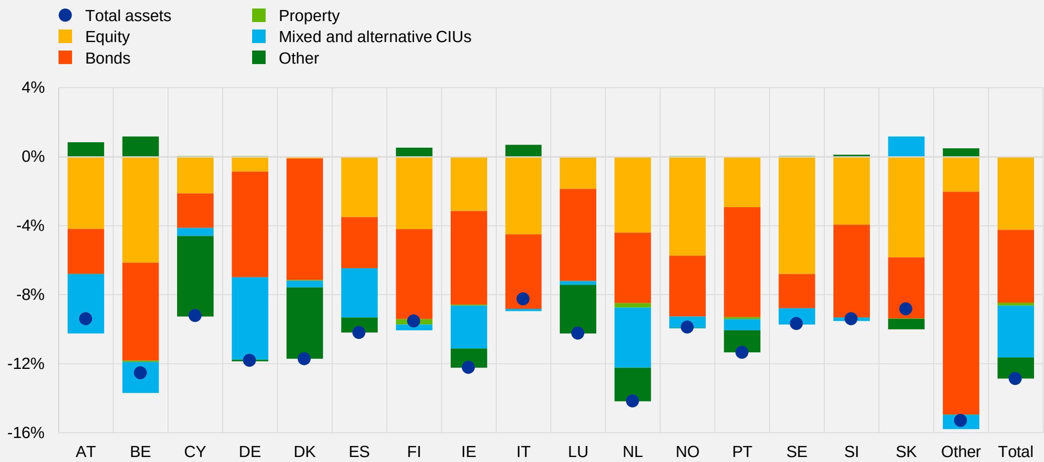
In 2022, EIOPA carried out its first climate stress test for the IORPs (Institutions for Occupational Retirement Provision) sector in the EEA to gain insight into the effects of climate risks on the occupational pension sector.[100] The scenario simulated a sudden, disorderly transition to a green economy, resulting in a sharp rise in carbon prices.

[100] The exercise contained 187 IORPs from 18 EEA Member States. For each member state the participating IORPs covered 60% of their IORP Sector. The coverage on the EEA level was 68%.

The exercise focused on the asset portfolios of IORPs, and the results show a sizeable impact under the adverse scenario, indicating that IORPs have a non-negligible exposure to transition risks, especially in the form of investments in climate-relevant sectors. The stress test scenario provoked a significant drop in the value of total assets of approximately €255 billion (or 12.9%) (Chart 2.1).

Chart A

Impact of the adverse scenario on assets



Source: EIOPA.
Note: Figures are based on the valuation of assets and liabilities on a marked-to-market basis, in order to enhance the comparability across European IORPs. The categories "Equity", "Bonds" and "Property" include indirect investments via investment funds. The category "Other" mainly contains derivatives, cash and reinsurance recoverables.

Due to the role of IORPs as pension providers, the risks affecting the asset side of their balance sheet will also have an impact on their long-term liabilities. The scenario considers shocks to market interest rates, which decreases the value of technical provisions across most Member States. This reduction does not fully offset the decline in the value of assets, resulting in a slight deterioration of their financial position overall. However, in most Member States the aggregate funding ratios of defined benefit pension schemes remain above 100% in the adverse scenario.

Funding ratios based on national methodologies decline for 13 out of the 18 participating Member States and by an average of 2.5 percentage points (from 122.7% to 120.2%). In the common methodology, the excess of assets over liabilities (EAL) declines by €75 billion (from €203 billion to €127 billion), resulting in a reduction of the funding ratio of 2.9 percentage points (from 119.9% to 117.0%).[101]

The stress test was complemented by a qualitative survey on climate change mitigation and adaptation measures, which revealed that while IORPs are becoming increasingly inclined to consider ESG factors in their investment decisions, they still encounter hurdles in allocating investments to climate risk-sensitive categories. Only 14% of IORPs reported using climate stress

101 Under the common methodology all assets are valued at mark-to-market, which explains why the adverse scenario has a greater negative impact compared to the national methodologies.

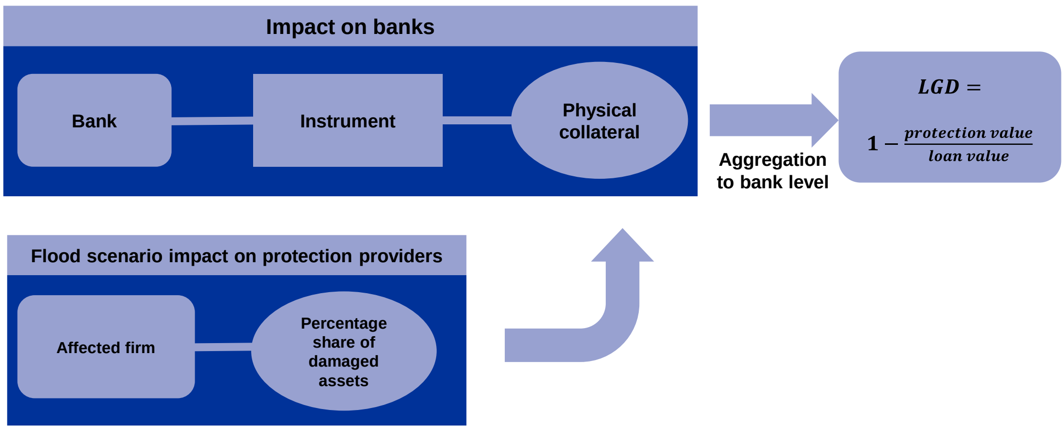
testing in their own risk management, though the results indicate that this subgroup performed better in the exercise than its peer group which does not conduct such testing. This finding suggests that climate stress testing helps IORPs position themselves better against transition risks.

3.3.2.2 Physical risk

Floods may directly impact the financial system via the destruction of physical assets pledged as collateral for loans, thus ultimately increasing the level of loss given default (LGD). Floods may therefore pose a threat to financial stability if large amounts of collateral are concentrated in areas prone to flood risk. There may also be indirect damages as a result of supply chain spillover effects that could impair the business operations of firms. The risks to financial intermediaries from the direct channel may be assessed in a scenario framework by translating damage to physical assets into impacts on portfolio LGD. Granular data on damage caused to the physical assets of affected firms in the flood risk scenarios are linked to data on banks' corporate loan exposures. In particular, information on the type and location of the physical collateral used in loan contracts can be exploited to calculate the scenario-dependent LGD changes (Figure 8).

Figure 8

Modelling the direct impact of flood scenarios on bank portfolios



Source: Deutsche Bundesbank. Data on loan instruments are from AnaCredit.
Note: Physical collateral includes residential and commercial real estate and other physical collateral.

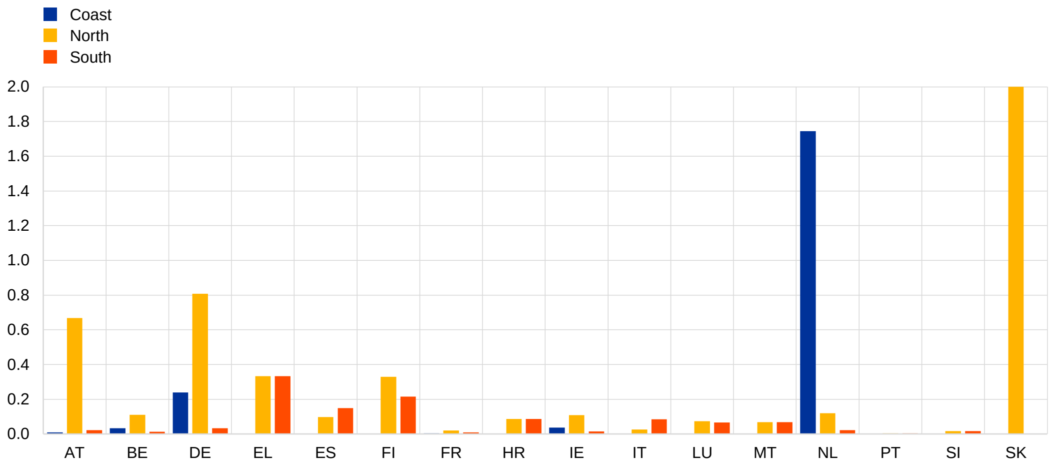
Using the flood scenarios constructed in the previous section as the input, LGD would moderately increase on aggregate, yet with substantial cross-country differences (Chart 28). The flooding scenario for Northern Europe has the largest impact on average. For example, LGD increases among German banks are three times higher in the "North" flood scenario compared to the "South" flood scenario. This also reflects the regional composition of the banks' corporate loan portfolios, in the sense that local German banks (and local banks in other countries) tend to focus their business operations in regions close to their branches.

The coastal flood scenario leads to LGD increases in only a few countries. Dutch banks are the most heavily exposed to LGD increases, due to their relatively large share of corporate borrowers identified as vulnerable to coastal flood events. An important limitation of the analysis is that protection measures against flooding (e.g. dams) are not included in the vulnerability assessment due to data and modelling restrictions. This is a key caveat, especially for the Netherlands, as the current risk of coastal floods is very low indeed (see, for example, Steinhausen et al., 2022; the **Delta Programme 2021** for details of Dutch flood defence measures). While flood risk impacts may appear moderate if aggregated at the country-level, vulnerabilities of individual banks may be substantial if large shares of the corporate loan portfolio are linked to firms affected by the flooding. At the same time, climate change is associated with large uncertainty, complicating the calibration and interpretation of physical risk stress tests.[102] The realisation of past events may thus not be a sufficient proxy for the future, increasing the scope for potentially larger losses as suggested in this exercise.

Chart 28

LGD impact of flood risk at country level

(Weighted average change in LGD relative to Q4 2022, in percentage points)



Sources: Deutsche Bundesbank calculations based on data from the Statistical Committee Expert Group on Climate Change Indicators, AnaCredit. Hazard and geolocational data taken from the European Commission Joint Research Centre (JRC), RIAD, and Huizinga et al. (2017)*.*
Notes: The charts show the LGD impact of the flood risk scenarios described in Section 2.3.1.2. Panel a) shows the country-level changes in LGD (weighted average relative to 2022Q4) disaggregated by type of flood scenario. Panel b) shows the sum of changes for all three scenario types. Loan-level results are first aggregated at the bank portfolio level, and weighted country-level averages of differences with respect to 2022Q4 are taken subsequently. Only countries with a minimum of five credit institutions present in the data are considered.

102 For an application of a flood risk stress test for the Netherlands and the treatment of uncertainty, see Caloia, F. and Jansen, D.-J. (2021), “Flood risk and financial stability: Evidence from a stress test for the Netherlands”, DNB Working Paper Series, No 730.

4 Policy considerations

A growing body of evidence and analytical tools provides a solid basis for a macroprudential strategy to address the systemic financial impacts of climate change. Such a strategy in the EU would focus primarily on addressing financial stability risks from the banking system as key lenders to the economy, complemented by direct measures to contain risk for borrowers, while also ensuring a perimeter which encompasses a growing role for non-bank financial intermediation. An encompassing set of macroprudential measures could, in this way, attenuate and mitigate the systemic risks posed by climate change to the financial system, noting that public policies, such as carbon pricing, remain the first-best policy for directly addressing the root anthropogenic causes of climate change itself (Krupnick and Parry, 2012; Stern 2021).

Operationalising such a macroprudential strategy across EU countries and sectors is possible with only limited adaptation of available instruments. The ECB/ESRB 2022 report provided some initial considerations on relevant macroprudential tools to tackle the systemic aspects of climate change. While the empirical basis for climate risk measurement and analysis has been growing stronger and policy discussion has been moving forward, notably in the EU (EBA 2023b; ESRB 2023), this chapter builds on previous work to provide a concrete menu of macroprudential options to tackle climate-related risks, both in the banking and non-bank financial intermediation sectors, including, in the latter case, specific suggestions for activating and calibrating these tools. We find that the EU macroprudential framework can already be applied in its current form to address climate-related risks, in lockstep with ongoing European and international initiatives and with certain targeted adjustments to enable a more efficient implementation process.

The chapter is organised as follows. Section 3.1 describes the rationale, goals and general features of a macroprudential strategy to address climate risks, which could guide the policy response at the European level, though also outside Europe. Section 3.2 presents the concrete policy options to operationalise the general strategy.

4.1 A general macroprudential strategy to address climate-related risks to financial stability

Rationale for a macroprudential approach to climate risks

Climate-related developments affect standard financial risk and, similar to any other financial risk, would be addressed through prudential policies. Both transition risks and physical risks affect individual financial institutions and the wider financial system (NGFS, 2020a). Moreover, as noted by the Basel Committee on Banking Supervision (BCBS), climate risks materialise through traditional risk categories used by financial institutions and reflected in the Basel Framework (such as credit risk, market risk, liquidity risk and operational risk). As these risks threaten the resilience of the financial system, regulators and supervisors have a role to play in assessing all possible risk channels and putting in place the appropriate micro- and macroprudential instruments to address both risk build-up and materialisation.

While climate may be conventional in its impact on financial risks, its effects can become systemic in novel ways. Climate-related risks have at least five unique characteristics. First physical risks, particularly chronic risks, are largely irreversible once they materialise. Hence, contrary to conventional financial risks from the business cycle, the ensuing financial shocks will not recede after the shock is reversed. Second, while physical climate risks embed high regional concentrations, the prevalence of chronic risk alongside strong self-reinforcing and interdependent acute natural hazards (wildfires, heatwaves, etc.) reduces the potential for risk diversification and the ability of private insurance providers to exploit diversification in providing coverage. Third, climate tipping points suggest the potential for non-linear outcomes when risks materialise (ECB/ESRB, 2021). Fourth, climate-related risks are both complex to measure and complicated to model (Holscher et al., 2022), not only because of the intricate relationship between transition and physical risks, which are not independent and amplify each other, but also due to a broader nexus between economic, financial and environmental feedbacks. Lastly, uncertainty over the scale and timing of climate risk materialisation, and the reliance on historical and imperfect data may cause us to underestimate climate risk impacts, thus contributing to an excessive build-up of risks and procyclical financing decisions.

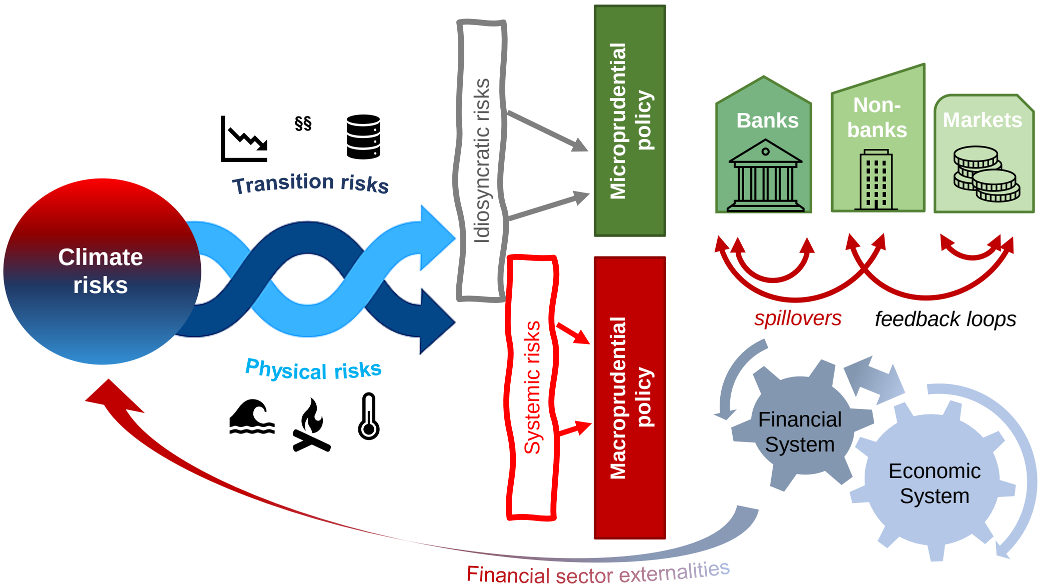
Climate-related risks can also be amplified by classic systemic risk channels. Climate-related risks can induce second-round effects within the financial system, thereby propagating shocks well beyond the initial exposure to these risks. These spillovers and risk transfers between the different sectors of the financial system can take multiple and unprecedented forms. For instance, ECB/ESRB (2022) found a near doubling of the average default correlation through counterparty risk channels, suggesting that a disorderly transition might not only result in direct losses for banks through direct credit or market risk channels, but also increase default correlation for a broader set of firms through counterparty risk, which limits the scope for hedging via diversification. The exposure of the non-banking sector and its contribution to the build-up of risks via contagion mechanisms or amplification mechanisms such as fire sales of stranded assets also calls for a system-wide policy approach. Furthermore, increased losses due to natural events might render insurance unaffordable or prompt insurers to stop offering coverage for certain perils and geographies. In more severe scenarios, it might even threaten the ability of insurers to meet their liabilities. This could have cascading effects well beyond the insurance sector, with contagion spreading to households and firms and directly affecting the balance sheets of banks as immovable collateral drops in value. Ultimately climate risks could spill over to fiscal risks. For instance, were insurance protection gaps (ECB-EIOPA 2023) to widen, natural catastrophes could trigger the activation of sovereign contingent liabilities (if the state acts as reinsurer of last resort or intervenes to ease tensions linked to credit risk in the banking sector). Equally, if transition risks materialise suddenly and unexpectedly, the economic outcome of asset stranding can also trigger activation of contingent sovereign liabilities, with possible risks to debt sustainability.

Financial sector externalities could also further aggravate climate change, thus increasing the level of systemic risk. Continued funding of high-emitting industries by individual banks can be characterised as a form of negative externality for the system, resulting in capital misallocation and ultimately contributing to climate risk build-up. Microprudential approaches, by focusing on the risk to individual institutions, are by construction less sensitive to these externalities. In contrast, a macroprudential approach that takes the interdependence of the financial system and climate change into account allows us to assess financial sector externalities (Holscher et al., 2022). Macroprudential policy is able to consider how these feedback effects from individual financial institutions feed through to systemic risk and also take account of the endogeneity of climate risks.

Within the prudential sphere, both microprudential and macroprudential policies have a role to play. Microprudential policies are key to ensuring the safety and soundness of financial institutions in withstanding idiosyncratic risks from climate change and the green transition (Figure 9). However, they fall short in addressing systemic spillovers across the financial system, have limited institutional scope, and may fail to identify and address the build-up of system-wide risk to financial stability (FSB, 2022). An effective prudential policy mix in addressing climate risks must be able to ensure the stability of the financial system, by triaging policy roles across regulators within the broader financial system, addressing interrelated risks across different sectors of the financial system, and preventing excessive risk build-up over time. As noted by Aikman and Barwell (2022), this might imply a delicate trade-off between ensuring resilience to climate-related risks (including "dual materiality" climate-related feedbacks from financial sector lending to the real economy) and an overzealous transition (creating scope for damaging credit contractions). In this vein, close dialogue between micro- and macroprudential authorities would ensure the most effective and coherent set of policies to address climate risks, given that microprudential and macroprudential policies are complementary, by addressing different aspects of climate risks. At the same time, both micro- and macroprudential policies rely on similar policy tools, implying a strong need to ensure consistency and avoid overlaps and making it especially important to clearly articulate the purpose of the policy tool of each respective authority.

Figure 9

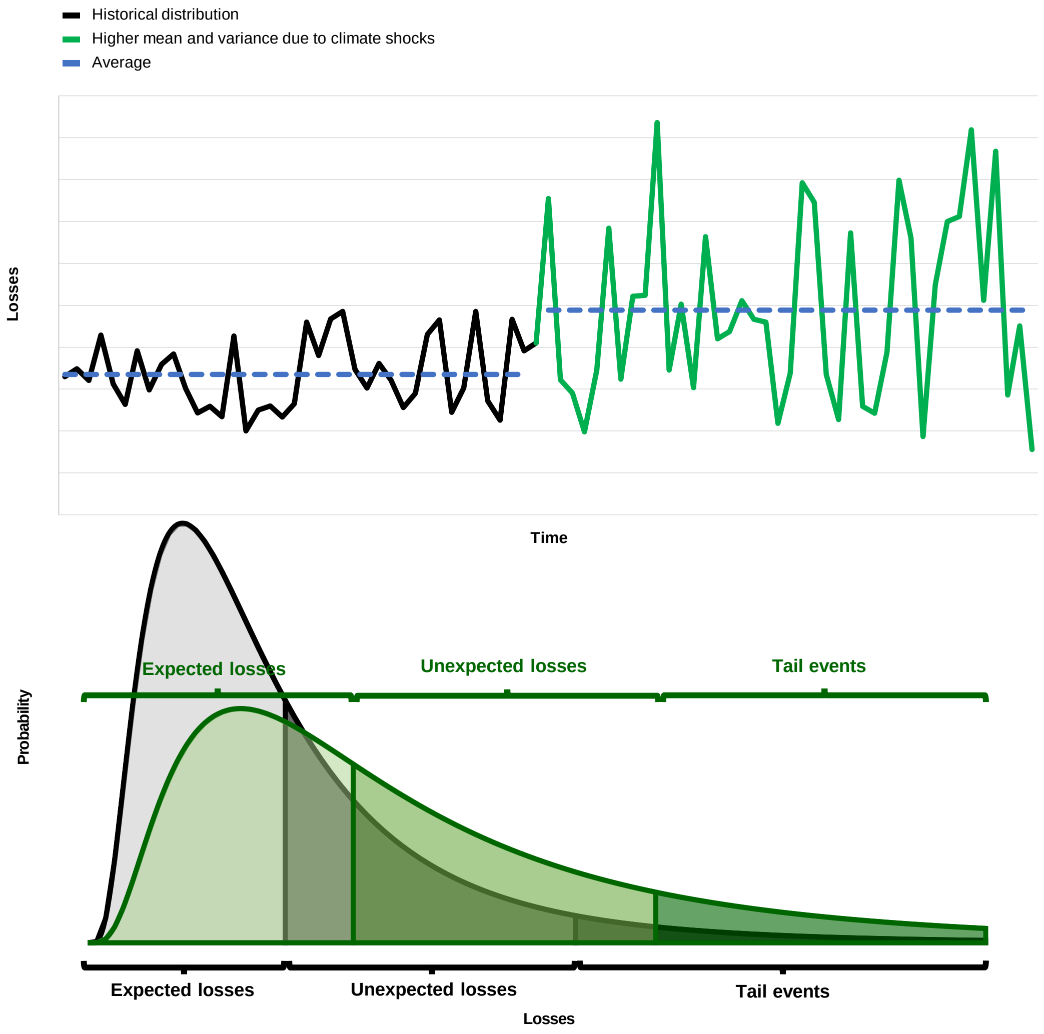
Prudential policies protecting the financial system from climate risks



Prudential policies will need to focus on risk management of financial institutions, while also ensuring resilience to a possible higher loss volatility. Borrowing the stylised framework presented by Holscher et al. (2022), climate risks could imply higher mean losses, a higher variance of losses, or a combination of both. If only expected losses increase as a result of climate change, the financial consequences can be managed through proper risk management and covered ex ante by appropriate risk-based pricing and provisioning. In this case, the appropriate prudential response is for supervisors to ensure that institutions have the right risk management capabilities in place and that provisioning is adjusted accordingly. However, as the literature suggests, climate change can also affect the distribution of losses (such as through a change in the frequency of severe weather events that introduces more volatility in terms of the frequency and severity of the economic impacts). In this context, higher capital requirements may be justified to respond to material increases in unexpected losses above the level accounted for under existing requirements. As higher loss variance also increases the probability of high-impact tail events ("fat tails"), the goal of macroprudential tools would be to build resilience against the now increased likelihood of low-probability but high-impact events that could threaten not only the viability of individual banks, but also pose risks to financial stability (Chart 29). The joint and coordinated use of both micro- and macroprudential measures would be self-reinforcing and ensure that the financial system is suitably protected from climate risks.

Chart 29

Stylised effects of climate shocks on the distribution of financial losses

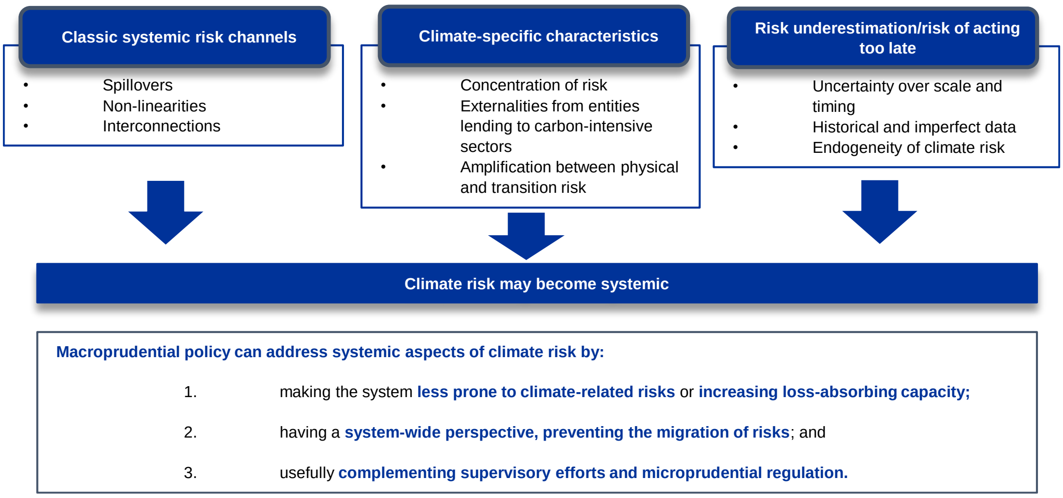


Source: Authors' own elaboration based on Holscher et al. (2022).

A cross-country and cross-sector approach at the European level is key to improving the overall efficiency of the policy response to systemic climate risks. As climate risks can and do vary from one country to another, adopting a common macroprudential approach at the European level (and ideally, at the global level) is key to preventing the fragmentation of policy responses across countries and thus make the general policy response more efficient (Figure 10). Moreover, as macroprudential policy considers both the banking and non-banking sectors as well as linkages between the two, it is meant to limit leakages and side effects caused by cross-sector arbitrage strategies. The coordination of policy responses across countries and sectors is key to ensuring efficiency in addressing systemic climate risks, by limiting the risk spillovers, uncertainty and distortions that can be caused by fragmentation.

Figure 10

The rationale for a macroprudential approach to climate risks



Source: ECB/ESRB.

Key features of a common macroprudential strategy

The broad aim of a common macroprudential strategy with a corrective and preventive arm is also applicable in the context of climate risk. Macroprudential policy action, while considering potential feedbacks between the real economy and climate risks, remains risk-based and stems from the identification of systemic risks related to climate change, potentially with a forward-looking and precautionary approach to prevent risk build-up. It can also be implemented in a way that does not prevent the transition of non-financial firms. An encompassing macroprudential framework can act on both the cross-sectional and time dimensions of climate risks, while being scalable and including forward-looking elements.

Macroprudential policy can be effective in addressing lender vulnerability linked to both an absolute and a relative increase in risks, with different tools better suited to each task. Given a general empirical finding of strong risk concentrations associated with climate, macroprudential policies would ideally address both general (absolute) and concentrated (relative) risks implied by climate change. If climate risks are considered to increase the absolute level of risks present in the financial system, activating macroprudential capital-based measures that cover all exposures among banks (such as macroprudential buffers) could be effective in making banks more resilient. Such measures could also account for potential future increases in credit risk stemming from a widening insurance protection gap. Meanwhile, if climate risks are considered to affect lenders via an increase in relative risks (such as an increase in risk concentration within specific sectors, geographies or counterparties, while the absolute risk level stays the same), then more tailored tools targeting exposures with a higher level of risk may be more appropriate, by increasing resilience based on identified pockets of concentrated risks or exposures only. These tools include, for instance, concentration charges, macroprudential buffers activated on the basis of concentration measures, or targeted macroprudential buffers (like the sectoral SyRB). In both cases, lossabsorbing capital in a macroprudential context is best suited to address "unknown unknowns" or a higher volatility of risks, particularly in the presence of high levels of uncertainty and inaction where provisioning is inadequate.

In order to limit the build-up of systemic climate risks, macroprudential policy can be effective in addressing an increase in the relative level of risks on the lender side, as well as an increase in either (absolute or relative) borrower vulnerabilities. If climate risks are believed to trigger an increase in the level of risks of certain subsectors only, while the overall level of risks in the financial system remains unchanged, several tools can be mobilised to pursue different goals. First, to enable relative risk containment, macroprudential policy could mobilise tools capable of addressing areas of risk concentration such as concentration thresholds and charges, targeted/sectoral buffers, or buffers based on climate-related concentration risk metrics. These tools can be calibrated so as to provide an incentive for financial institutions to reduce the concentration of their exposures to climate risks, without curtailing the financing made available to firms trying to transition towards a more sustainable business model. Second, to enable risk containment at the borrower level, BBMs can usefully complement capital-based measures to address an absolute or relative increase in risks. Indeed, if climate risks are assessed to provoke an increase in absolute risks not already accounted for in market prices, the inclusion of climate risk parameters in BBM calibration models should lead to an increase in PD or LGD, which could warrant tighter limits. To a lesser extent, BBMs could also be effective in addressing relative risk containment by enabling banks to limit their exposure to the riskiest loans. BBMs could be differentiated, with relatively tighter limits for loans highly exposed to climate risks, and relatively looser limits for other loans. These measures would take time to have an impact, as they apply only to new loans. However, the uncertainty and potential costs of identifying physical and transition risks suggest that banks would have little incentive to internalise these risks, and thus BBMs could be a relevant tool to prevent excessive risk-taking among banks by anchoring credit standards.

For non-banks, addressing market failures from informational asymmetry or moral hazard through enhanced transparency could provide an immediate way to limit risk build-up as a nascent toolkit is developed. While the general principles outlined above (progressivity, complementarity with other policies, and precautionary approach targeting both absolute and relative risks) fully apply to non-bank financial institutions, macroprudential policy is in general less developed for the non-banking sector, with reflections on addressing climate and broader ESG risks at the microprudential level still ongoing. Looking further ahead, activity- or entity-based tools currently under discussion for banks (e.g. tools addressing concentrated risks) might also be considered for the non-banking sector. In the meantime, tools to address informational failures can be used to improve systemic risk by ensuring transparency in the markets and limiting asset repricing risks. Policies to improve levels of reporting and address potential greenwashing risks are therefore an integral part of the macroprudential toolkit for addressing climate risks. Lastly, tools for the banking sector can also contribute to a certain extent in addressing risks in the non-banking sector. Indeed, tools like the SyRB or BBMs can also help build general resilience against a widening insurance protection gap, which would increase banks' potential losses.

In an environment of imperfect information and uncertainty, macroprudential policy responses need to weigh the cost of early action based on imperfect information, against the risk of acting too late. There is scientific consensus that climate risks are inevitable (IPCC, 2023). However, the severity of these risks and the form they ultimately take remains uncertain and depends on whether and how the transition to a net zero economy occurs. Given this uncertainty, a wait-and-see approach might well be the best course of action until more information becomes available. However, the radical uncertainty characteristic of climate risks means that the past is not a reliable guide for the future manifestation of climate risks, and therefore a prudential response conventionally built around a framework of backward-looking information would by design fail to keep up with actual level of risks. As a result, we may not achieve the required level of resilience or a timely reduction of exposures to climate risks until it is too late. In contrast, a precautionary approach informed by forward-looking information might allow us to escape the inaction bias and avoid the risk of doing too little, too late. A macroprudential approach is especially well suited to achieving this task, because its aim is to reduce "tail risks" – i.e. minimise the probability and severity of low-probability, but high-impact events. As such, it is more likely to identify as significant risks that might never materialise than to fail to identify real threats. In any case, climate risks should not be held at higher prerequisites for action in terms of data availability and quality than those applied to other types of risks already addressed through macroprudential policy, such as risks to residential or CRE. And while the process of assessing the systemic impacts of climate risk might not be fully mature in all jurisdictions, our ability to measure and model the impacts of climate risks on the financial system has greatly improved in recent years, as described in Chapter 2.

To address the complex and evolving nature of climate risks, macroprudential policy might rely on a nimble approach, with adaptive tools or sandboxing. Sliding adaptive requirements, in particular, might be set differentially, depending on the materiality of specific climate-related risks through time, or in a given jurisdiction. A common macroprudential framework can be flexible and updatable to changing circumstances, on the side of both climate risks and economic developments. Indeed, the prevailing economic outlook may condition the pace of climate adaptation, and climate risks hinge on the ambition and speed of mitigation measures. Therefore, it should be possible to scale up macroprudential tools over time, as transition or physical risks increase, and also to scale them down if the economic and political outlook are seen to address climate change risks efficiently or if, at firm level, the formulated transition plan are credible.

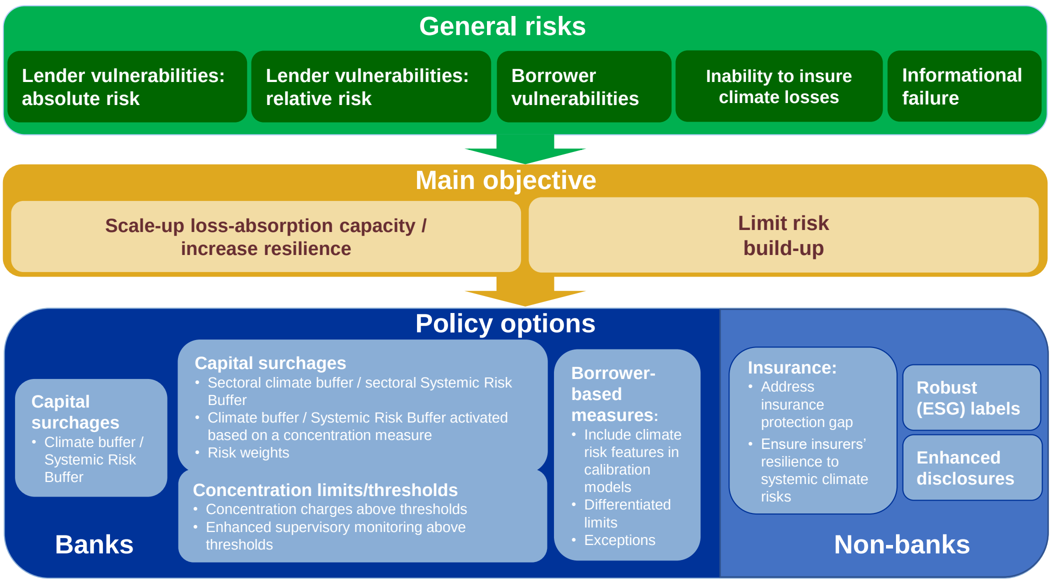
An efficient macroprudential response can be gradual, dynamic and based on aligning incentives with the prudential goals, rather than imposing restrictive capital requirements indiscriminately. An efficient and dynamic approach is key to avoid burdening financial institutions disproportionally by asking for more capital when they need to finance the transition. Carving out exposures on a credible transition path from the application of macroprudential measures, while technically challenging and demanding in terms of granular data, would have the desirable effect of avoiding unintended restrictions on transition financing. Similarly, a forward-looking approach when calibrating instruments would allow us to better capture the evolving nature of the risks. Similarly, when addressing physical risks, unintended effects on adaptation financing should be avoided.

A macroprudential approach is well suited to cover a time horizon which captures both physical and transition risks as they materialise. The time horizon for the materialisation of transition risks appears conceptually closer to the conventional use of prudential tools, given their medium-term horizon and affinity to the build-up of risks over the business cycle. On the other hand, the time horizon for assessing chronic physical risk is typically long, which would in turn imply the need to build resilience over very long time horizons; much longer than is conventionally the case for macroprudential measures. The coexistence of these different time horizons, and the complex interactions between physical and transition risks, pose an additional challenge to an efficient design of macroprudential policies, and supports the case for a flexible approach that builds resilience where needed and can be adjusted over time to reflect the shifting realities.

Ultimately, a broad and timely collective policy response to prevent and mitigate the impacts of climate change remains the first line of defence to avoid the systemic consequences of climate change. As shown in the ECB's recent second economy-wide climate stress test, the sooner and faster we complete the necessary green transition, the lower the overall costs and risks will be[103]. Macroprudential policies can complement microprudential policies to help ensure that the financial system is sufficiently robust and resilient in the face of climate-related financial risk (Figure 11) and able to fulfil its role of financing the real economy and the transition to climate neutrality. However, they are no substitute for the ambitious public policy measures that are needed to mitigate climate change: the first-best policy to avoid the risks of climate change is to stop it from happening.

Figure 11

From general to specific macroprudential risks, tools and objectives



Source: ECB/ESRB.

103 See De Guindos, L. (2023).

4.2 Operationalising a macroprudential framework with existing instruments

4.2.1 Policy tools for the banking sector

4.2.1.1 Measures to address climate-related concentration risk

Mounting empirical evidence shows that banks with higher exposures to climate-related concentration risk (CRCR) have a higher risk of incurring sizeable losses, with 80% of total corporate emissions originating from only four sectors (mining, manufacturing, electricity, and retail trade). These account for 40% of banks' credit exposures[104], while more than 60% of banks' interest income is derived from NFCs operating in carbon-intensive sectors[105]. A comparison between banks that have a similar share of exposures to high-emitting firms but differing concentration values reveals that a substantial share of expected losses in a disorderly transition scenario relates to the degree of portfolio concentration[106]. Results of simulations based on the 2023 ECB top-down climate stress test presented in Chapter 2 show that banks with higher concentration risk (as measured with a widely used indicator of concentration, namely the Herfindahl-Hirschman Index, modified to account for the fossil fuel consumption (intensity) of their loan portfolio[107]) experience losses up to two times larger than their less concentrated counterparts (see Chapter 2, concentration risk part). Under this scenario, the most concentrated banks record losses totalling 2.25% of their corporate loan portfolio. Higher concentration is associated with higher bank losses. This relationship holds no matter the degree of transition risk exposure. Regarding physical risk, exposures to physical hazards concentrated at the regional level appear to be more relevant for weakly capitalised and/or less profitable banks, which may threaten their soundness should one or more geographically concentrated events occur (ECB/ESRB 2021).

CRCR appears not to be completely captured by the Pillar 1 regulatory framework, although the materiality of this gap and the eventual need for policy action remain unclear. CRCR is not specifically addressed by the large exposure framework (LEX) under Pillar 1 of the Basel framework.[108] This framework aims to address large exposures to protect individual banks from large losses resulting from the sudden default of a single-name counterparty or a group of connected counterparties.[109] By design, it does not capture other forms of concentration which are

---

104 See ECB (2021).

105 See results of the **2022 ECB Banking Supervision Climate Stress Test**.

106 See ECB (2022).

107 The carbon-weighted Herfindahl-Hirschman Index (cwHHI) of a bank is calculated as follows (where i stands for firm i) and w is a climate weight, consisting of borrower fossil fuel consumption $cwHHI = \sum_{i=1}^{N} w_i \frac{exposure_i^2}{total\ exposures^2}$): .
For more information, see Chapter 1 on data and measurement.

108 The LEX framework is part of the EU prudential framework under Article 395(1) CRR. It can also be used for macroprudential purposes (Art. 458 CRR).

109 Minimum capital requirements (Pillar 1) under the Basel risk-based capital framework implicitly assume that a bank holds infinitely granular portfolios, meaning that no form of concentration risk is considered when calculating capital requirements. Contrary to this assumption, idiosyncratic risk due to large exposures to individual counterparties or groups of connected counterparties may be present in banks' portfolios. The LEX framework aims to address this residual risk. See BCBS, Basel Framework, LEX Standard, LEX 10, Definitions and application.

particularly relevant for CRCR, such as concentration towards firms in the same high-risk sectors (e.g. lending to unrelated firms engaging in high-emitting activities) or geographical concentrations (e.g. lending to unrelated firms operating in high-risk geographical areas). That said, part of CRCR may be captured under Pillar 2 in accordance with the Basel framework as part of wider dimensions of concentration risk, such as sectoral and geographical concentrations. The actual materiality of the gap in the regulatory framework remains the object of ongoing investigation: the Basel Committee is currently working on options to address climate-related concentration risks holistically via a combination of Pillar 1, 2 and 3 measures. Furthermore, EBA will propose amendments to its supervisory reporting and disclosures framework, including the progressive development of environment-related concentration risk metrics.[110]

Macroprudential authorities need to account for concentrated climate risk exposures. CRCR could affect exposures to multiple counterparties exposed to the same climate-related (transition or physical) risk drivers. This includes large exposures, though also some otherwise unrelated exposures with shared sensitivity to physical risks, due to geographical location or activity. Seemingly unrelated exposures can be part of the same economic sector and can share production characteristics, thus making them vulnerable to the same transition risks. These commonalities increase the likelihood of a tail event with potentially large losses. This could not only threaten the financial condition of individual banks or their ability to maintain critical services or functions, but also have system-wide implications. Similarly, overlapping portfolios may amplify concentration risk on a system-wide level, such as if firms with no economic links were exposed to the same physical risk hazard.

Concentration thresholds could act as a quantitative ceiling intended to limit the extent of individual firms' vulnerability to CRCR. Measures based on concentration thresholds would aim to reduce the likelihood that a tail event, where common climate-related risk drivers affect multiple seemingly unrelated exposures spread across different portfolios of different institutions, threatens the viability of the institution and the financial system as a whole. Such thresholds would aspire to either discourage or outright prevent further increases in systemic risk and, if well designed, could incentivise banks to reduce exposure concentrations, thus helping to make them more resilient.[111]

Supervisory measures and/or a capital surcharge could be activated if the underlying exposure or risk metric reaches a predefined value. Breaches of thresholds could trigger enhanced monitoring and, if deemed necessary (such as in the absence of mitigating steps), corrective supervisory action, perhaps by setting requirements to reduce the size or number of vulnerable exposures, or by increasing capital requirements, or a combination of both. Various configurations of prudential measures are theoretically possible in this context. The breach of thresholds could for instance trigger an intensified supervisory dialogue where banks could be required to present plans on how to avoid risks stemming from CRCR.[112] In the absence of sufficient mitigating action, additional capital charges could be considered as a last resort. These

[110] See EBA (2023b).

[111] While a limit is a restriction or a maximum value, a threshold could be exceeded.

[112] Bucketing based on the distribution of concentration measures could help to identify the most vulnerable banks and guide supervisory action. Chart 30 reveals that by 2025, banks scoring above the 75th percentile of the cwHHI record 33% higher cumulative losses than the next three lower buckets and almost 300% higher losses than the least concentrated banks. The grouping of low, medium and high vulnerability to concentration risk could be used as a basis for escalatory supervisory scrutiny. For instance, supervisors may demand no further action from the bottom quintile banks, engage in enhanced dialogue with the medium quintiles, and demand a plan to reduce concentration exposures from the top quintile.

could take the form of a capital add-on above certain concentration thresholds, via adjustments to risk weights for assets above concentration thresholds, or via a tailored concentration-based buffer. From a macroprudential perspective, the latter option would be particularly effective in capturing systemic aspects of CRCR. In the EU, such a buffer could take the form of a SyRB, meaning that it would be applied to all exposures of banks that exceed a certain concentration threshold. Given its macroprudential relevance, this option is discussed in detail in Section 3.2.1.2.

While various metrics could in principle be used to define concentration thresholds, relative metrics offer a number of practical advantages. Theoretically, possible metrics of concentration risks include size of exposures to high-emitting firms or to vulnerable sectors or geographies, both relative to portfolio size or eventually risk-weighted assets. However, defining absolute values for thresholds proves challenging, due to a lack of historical data. Another option would be to define concentration thresholds relative to the distribution across banks. An example of this approach is the carbon-weighted Herfindahl-Hirschman Index (cwHHI) described in Chapter 2.[113] Concentration metrics could then be calculated based on a different definition of concentrated exposures, including single-name exposures to individual high-risk counterparts or the sum of exposures to regions and/or (sub)sectors. While using individual loan exposures might be better suited to tracking correlations, monitoring the sum of loan exposures could enable macroprudential regulators to capture the banking sector's overall vulnerability to CRCR. To estimate the impact of a given threshold, authorities could rely on simulated losses based on climate stress testing or scenario analysis.

A simulation exercise based on the ECB's 2023 top-down economy-wide stress test suggests that thresholds set at the current concentration level of the 75th percentile would lead to a significant reduction in transition-related losses. This simulation exercise compares losses due to a transition shock for banks above and below a certain threshold, using the above-mentioned cwHHI to measure concentration. The findings presented in panel a) of Chart 30 indicate that the 75th percentile may be an effective threshold. Based on this simulation exercise, panel b) of Chart 30 reveals that if concentrated banks starting with concentrations higher than the 75th percentile reduced their lending to the level of the proposed threshold, they could reduce their climate-related losses between 7.4% and 9.1%. Naturally, a higher threshold would correspond to a lower reduction in losses as the overall exposure to climate risk remains more elevated. Hence, prudential authorities face a trade-off: higher thresholds may be less intrusive but come at the cost of higher losses if CRCR materialises. As banks pare back their portfolio concentration, relative thresholds based on percentiles will automatically decrease, making the original thresholds poor signposts for concentration. Therefore, following the first iteration, subsequent re-assessments of the thresholds would need to be informed by an analysis of absolute risks, such as through climate stress testing.

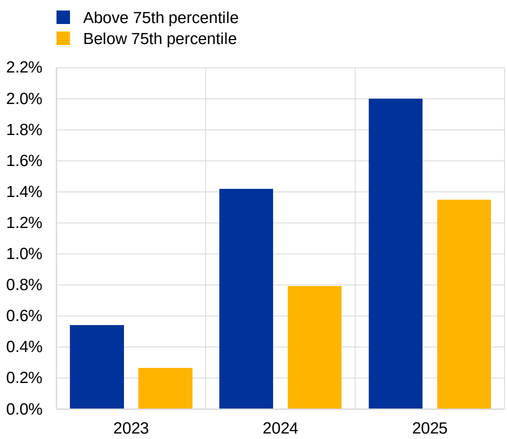
[113] See also ECB (2022) and footnote 107.

Chart 30

Impact of 75th percentile concentration threshold on transition-related losses

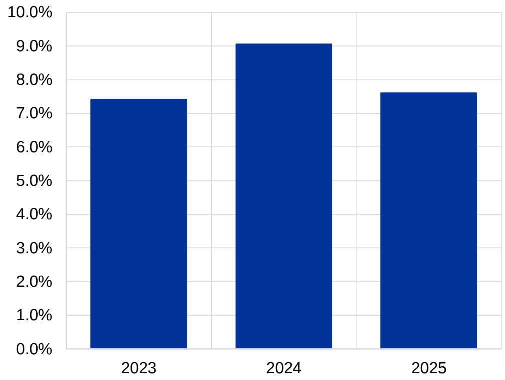
a) Projected cumulative losses relative to corporate credit portfolio above versus below concentration threshold (75th percentile)

(x-axis: year; y-axis: losses/corporate loans portfolio)



b) Projected decrease in cumulative losses caused by reducing concentration to the level of the threshold (75th percentile)

(x-axis: year; y-axis: percentage decrease in losses due to compliance)



Source: ECB.
Notes: Sample of 100 Significant Institutions (SIs). Calculations based on the 2023 top-down economy-wide stress test. To identify losses due purely to climate risk, projected losses in the absence of a climate shock are subtracted from losses in the presence of a climate shock. The resulting delta is reported. High-emitting firms are defined as firms scoring above the 75th percentile for relative emissions. To estimate the degree of compliance, a diversification exercise as proposed in ECB (2022) is conducted. The share of exposures allocated to high-emitting firms may not exceed the 75th percentile. If this limit is exceeded, exposures to high emitters are pro rata redistributed to non-high-emitting firms until the limit is satisfied. The change in expected losses due to diversification is then attributed to compliance with the limit.

To reduce possible unintended side effects on transition financing, the design of CRCR thresholds might need to incorporate some degree of forward-looking data. The use of backward-looking metrics to define thresholds could effectively impede a further risk build-up of climate risks relative to the status quo. However, uncertainty about the size of the risks is high and depends to a considerable extent on the planned transition pathways, which are not necessarily the same in each jurisdiction and across firms. Therefore, basing such thresholds on purely backward-looking information would likely fail to properly calibrate the prudential limits to the optimal concentration, which could also generate unintended adverse effects on transition financing by constraining banks' lending capacity to firms needing to transition. To avoid such cliff effects, the limits could be linked to forward-looking metrics, such as transition plans.[114]

[114] A similar argument is made by Coelho and Restoy (2023).

4.2.1.2 Systemic risk buffer

The SyRB has been identified as a potential macroprudential tool to address systemic aspects of climate risks in the EU. The European Commission has explicitly acknowledged that the SyRB can be used in the region to prevent and mitigate macroprudential or systemic risks stemming from climate change.[115] Additionally, the ECB/ESRB (2022) have noted that the SyRB, whether applied generally or sectorally, can be employed to mitigate the build-up of risk concentration while simultaneously making banks more resilient to climate risks.

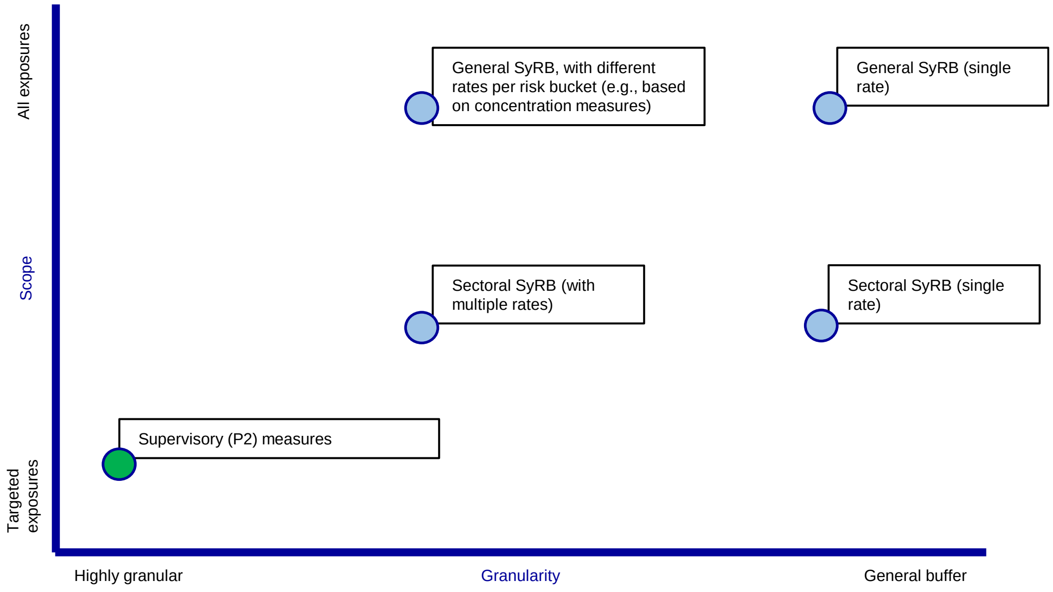
Potential applications of the SyRB

The embedded flexibility of the SyRB framework allows for a range of design options, depending on the choice of exposures in scope, buffer rate structure, activation, and calibration approach. Various combinations of these design variables are possible, depending on the nature of the climate risks to be addressed, and the SyRB can be configured so as to provide operational flexibility to account for possible policy trade-offs. Focusing on the buffer rate structure, at one end of the spectrum would be a general SyRB applied to all banks with a single rate, while at the other end would be a tailored SyRB calibrated to reflect the climate risk exposures of individual banks. Several options can be conceived in the continuum between both ends, with multiple rates applying to different risk buckets or different sectoral segmentations. Similarly, the choice of the climate risk exposures to which the buffer would apply (ranging from the exposures of all banks to smaller subsets of riskier exposures), as well as the relevant criteria for activation and calibration approaches, provide further levers for tailoring the buffer to specific prudential needs. Figure 12 provides a stylised presentation of the key SyRB design options along the two main dimensions described above.

115 See Recital 36 of **Proposal for a Directive of the European Parliament and of the Council amending Directive 2013/36/EU as regards supervisory powers, sanctions, third-country branches, and environmental, social and governance risks, and amending Directive 2014/59/EU** (CRD6).

Figure 12

Stylised presentation of key SyRB design options



Source: ECB/ESRB.

Each design option has advantages and drawbacks, implying policy trade-offs and making the choice ultimately conditional on the specific risk combinations to be addressed. A single buffer rate would be simple to administer and could deliver a general increase in system-wide resilience against climate risks amid high uncertainty over when exactly they might materialise. At the same time, the single rate structure would dilute the effectiveness of the measure by failing to address risks directly where they are, and increase the costs associated with higher capital for the whole banking sector (Hiebert and Monnin, 2023). In contrast, institution-specific buffers could be tailored specifically to the exposure of each bank, thus more efficiently addressing the risks where they are located. Such a design would have the advantage of aligning the incentive for each institution to reduce its exposure to climate-related financial risks in order to limit the buffer requirements. The downside is that the implementation side would be more complex, requiring us to determine, for each bank, the right buffer rate depending on the size of the risk exposure. Furthermore, an institution-specific buffer warranted on macroprudential grounds could overlap with microprudential measures to address idiosyncratic risk, such as Pillar 2 add-ons. These downsides could be reduced by having multiple rates applying to different risk buckets or sectors: banks more exposed to concentration risks would face higher buffers, similar to the approach used for the existing systemic buffers. Alternatively the buffer could be targeted to those segments of exposures most exposed to climate risk. Multiple rates for different buckets would be operationally simple, and would have the advantage of providing dynamic incentives for banks to reduce their exposures at risk in order to remain in the lower bucket and thus benefit from lower capital charges. Overall, the following three design options stand out as particularly promising for addressing climate-related risks:

A general SyRB applied to all banks would be a flexible tool for increasing overall resilience to climate-related financial risks and providing an additional system-wide cushion against the related increase in unexpected losses. A broad application of the SyRB could increase the overall resilience of the banking sector and hence reduce the potentially systemic repercussions of a materialisation of climate risks. Furthermore, the tool is readily available, with only minor needed to the existing framework, and it could also be applied on a flexible basis to certain groups of banks. At the same time, it would be relatively untargeted compared to measures that directly target the exposures subject to climate risks or the institutions most exposed to climate risks: this blunt nature also provides only a limited incentive for banks to align their portfolio choices with the objectives of an orderly transition. These downsides could be reduced by designing a general SyRB with multiple rates applying to different risk buckets: while preserving the general nature and broad impact of this design option, multiple rates would reduce efficiency losses compared to a single rate SyRB, while also providing some degree of dynamic incentives for banks to limit their exposures below the bucket thresholds. Box 4 below provides a detailed description of how this design might be applied.

A sectoral SyRB that applies only to the subset of bank exposures highly affected by climate risk seems especially suited to target climate-related risks, which are often characterised by their sectoral or geographical concentration. This targeted measure would adjust the capital charge proportionately, based on a bank's exposure to climate risk. In doing so, a sectoral SyRB would influence the relative cost of lending to different sectors, thus reducing the appeal of loans more exposed to climate risk. The aim here is to limit risk build-up and concentration while making the banking system more resilient. While the sectoral SyRB would have the advantage of being a more targeted option compared to a general buffer, as it focuses solely on exposures subject to climate risk, it is not without shortcomings. First, its optimal implementation would require a review of the existing EBA guidelines. Second, it would apply only to domestic exposures, meaning it would in principle not address risks arising from foreign exposures.

A third design option would be to implement the general SyRB in a way that specifically targets the concentration of exposures that are more sensitive to climate-related financial risks. In this case, the buffer rate could be differentiated based on bank-level measures of climate-related concentration risk (CRCR; see Section 3.2.1.1). Thus, we could make the general SyRB a more targeted measure by setting thresholds for concentration and associating different levels of the buffer to be applied to all exposures of individual banks or groups of banks that exceed those thresholds ("concentration-related SyRB"). A key advantage of such an approach is that, on top of broadly increasing the resilience of exposed banks via an additional buffer, it would also discourage excessive concentration and limit the build-up of risk that could make the financial system vulnerable to common shocks. By targeting and discouraging high concentrations of CRFR exposures, the financial system would be better able to withstand one of the main channels of systemic amplification of climate-related risks.

A key challenge across all three options is the need to define sufficiently granular risk exposures to avoid unintended consequences on transition financing. For physical risk, this would mean defining the appropriate degree of geographical granularity. For transition risk, how we define the scope of exposures would have far-reaching implications for the functioning of the buffer. A conceptually and operationally straightforward approach would be to define high-risk exposures simply by identifying high-risk sectors (which is the predominant approach in the existing literature).[116] This approach has the advantage of being both simple and transparent, in that additional data needs for such an option would be relatively low. The downside is that it assumes that all exposures to a given sector are equally high-risk, thus failing to recognise that firms in high-emitting sectors might over time significantly reduce their transition risk exposure by reducing emissions and shifting to greener technologies. By ignoring such within-sector variability, a buffer thus designed might discourage lending to all firms operating within current high-risk sectors, irrespective of the efforts made by individual firms to decarbonise and reduce their transition risks. This might be particularly problematic, as firms in current high-emitting sectors are arguably those in greatest need of transition financing. Box 3 presents a simple back-of-the-envelope estimation of the impact on credit supply of a climate SyRB based on a sectoral classification of exposures. The analysis confirms a negative impact on credit growth, although the magnitude would be modest given realistic estimates of the increase in capital requirements.

Box 3
Estimating the impact of a climate systemic risk buffer on credit supply

When a SyRB for climate purposes is introduced, the associated capital increase will enable financial institutions to absorb unexpected losses if and when a climate-related shock materialises. However, an inherent policy trade-off of capital-based macroprudential measures is that the required increase in capital might negatively affect credit supply in the short term. This negative effect of higher capital requirements on credit supply is widely documented in the literature, although the precise estimates depend on the sample period and country under investigation (Aiyar et al., 2014; De Jonghe et al., 2020; Favara et al., 2021; Gropp et al., 2019) and state of the macro-financial environment (Lang and Menno, 2023).

An illustrative calibration exercise based on the ECB climate stress test (presented in more detail in Box 4 below) estimates that the introduction of a SyRB targeting transition risk among euro area significant institutions would imply an increase in aggregate capital requirements of 0.59 percentage points. In this box, we estimate the potential impact of introducing this climate SyRB on credit supply, using evidence from the existing literature (Table A). We first show the estimated effect of a 1 percentage point increase in capital requirements (as a percentage of risk-weighted assets) on annual credit growth, as documented in each of the papers. Subsequently, we apply these estimates to our climate SyRB application. We find that the potential impact on credit growth ranges between negligible and minus 6 percentage points. However, according to Lang and Menno

[116] In the academic literature, transition risks are generally identified according to various sector-based classification systems: this choice implies that transition risk concentration is assumed to be sector-specific. This means that as long as a bank is exposed to a counterpart within a sector labelled as high-risk, that exposure will remain high-risk, no matter what the future trajectory and investment decisions of that company will be. In such approaches there is no room for so-called transition finance, and any lending to a “bad” sector (i.e. an emission-intensive sector) is by default assumed as high-risk. Such approaches ignore the fact that high-emitting firms, or firms with a credible transition plan, may become low-emitters in the future. Another strand of literature has highlighted that the existing classifications of economic sectors were not designed to capture climate risks and are generally unsuitable for identifying those economic activities exposed to transition risk (see, for example, Battiston et al. (2017, 2022) and Faiella and Lavecchia (2020)). Battiston et al. (2017) define a correspondence between sectors of economic activity and five newly defined climate-policy-relevant sectors (CPRSs) (fossil fuel, utilities, energy-intensive, transport and housing) based not only on their GHG emissions, but also on their role in the energy supply chain, and the existence in most countries of related climate policy institutions. This allows for a more accurate, though still imperfect, identification of the sectors most exposed to transition risk.

(2023), the credit growth impact is expected to be situated towards the lower end of these estimates if the climate SyRB is introduced in non-stressed times.

Table A

Potential impact of a climate SyRB on aggregate credit growth

Paper	Impact of 1 ppt increase in capital requirements	Period	Geography	Impact of climate SyRB
Aiyar et al. (2014)	-5.7 to -8 ppt	1998-2007	United Kingdom	-3.39 to -4.75 ppt
De Jonghe et al. (2020)	-2.29 ppt	2013-2015	Belgium	-1.36 ppt
Favara et al. (2021)	-3 to -4 ppt	2014-2017	United States	-1.78 to -2.38 ppt
Gropp et al. (2019)	-9 ppt	2010-2013	Europe	-5.35 ppt
Lang & Menno (2023)	-0.1 to -10 ppt	2005-2019	Euro area	-0.06 to -5.94 ppt

Source: Simoens et al. (2023).
Notes: All estimates are expressed on an annual basis. We use the estimate for term loan credit growth from De Jonghe et al. (2020). Favara et al. (2021) and Lang and Menno (2023) measure an effect on outstanding/committed credit in per cent instead of a percentage point (ppt) impact on credit growth. For comparability reasons, we therefore assume a normal credit growth of zero per cent in order to present their estimates as a ppt impact on credit growth. For Gropp et al. (2019), we combine the estimates for the impact of participating in the EBA 2011 capital exercise on capital and on credit growth.

Granular definitions of transition risk exposures accounting for firm-level specificities and transition trajectories would greatly enhance the efficiency of a capital buffer for climate risks, but are operationally complex. Two such approaches could be considered (Coelho and Restoy, 2023). The first would be to define the scope of application at the firm level by assessing the current and future emission profiles of the borrowers. This forward-looking assessment could be based on transition plans demonstrating how individual firms plan to adjust their emission profile going forward. A second, even more granular option would be to define the scope of application at the level of specific projects/activities rather than counterparties. Under this approach, banks and prudential authorities would aim to distinguish transition finance from other types of lending to carbon-intensive counterparties in order to mitigate transition risks. Such a framework would be challenging, as it would be predicated on the existence of a granular taxonomy of high-risk exposures, and on the availability of related data to allow banks and supervisors to assess whether a specific exposure falls within the scope of application of this instrument.

Data granularity issues are particularly acute for the sectoral SyRB, but less so for the concentration-related SyRB and the general SyRB. A concentration-related SyRB could be based on institution-specific concentration measures, without the need for granular differentiation. If properly calibrated, a concentration-based SyRB would still enable banks with diversified portfolios – which applies to the majority of large and medium-sized European banks – to continue financing companies in high-risk sectors, if the bank considers this risk tolerable (e.g. in the light of the borrower's transition plans). The issue of data granularity is also less relevant for the general SyRB, as it would be activated in response to country-level aggregated indicators. Lastly, the application of a SyRB in specific geographical areas would carry the risk of distorting competition and creating an uneven playing field among companies – ceteris paribus – active in different geographical areas. To cater for this, the design of the SyRB could foresee targeted exclusions of very small intermediaries with a high sectoral concentration to ensure continued support for local economies.

Potential amendments to the existing SyRB framework

The introduction of the sectoral SyRB under CRD V was accompanied by a mandate for the EBA to develop a set of guidelines aimed at harmonising the design of appropriate subsets of sectoral exposures. The resulting Guidelines build on the prerequisites set out in paragraph 5(f) of CRD Article 133[117], which establishes four high-level sectoral exposures[118] to which a SyRB may be applied.[119] The exposure to transition risk could potentially be approximated by using the economic sector of the debtor and the exposure to physical risk using the geographical location of the loan collateral.

The classification system set out in the Guidelines might need to be reviewed to accurately and consistently identify the sets or subsets of exposures to climate-related financial risks. This is because the level of granularity provided by the Guidelines in the definition of economic sectors (NACE Rev 2 level 1, 21 categories A to U) – and, to a lesser extent, of geographies (NUTS 3, subregion) – is currently not sufficient to capture exposures to climate risk. A higher level of granularity is not permitted under the current Guidelines, implying that a sectoral SyRB would need to be applied at a level of aggregation insufficiently granular to distinguish (and target) climate risks within the given sectoral and geographical classifications. Should the competent authorities wish to implement a sectoral SyRB for climate risks as discussed above, they would either have to do so with the suboptimal degree of granularity currently prescribed by the Guidelines or would need to accept a justified divergence from the EBA Guidelines. Ideally, firm-level sector classifications such as NACE level 4, or ideally even more granular activity-level data, would be needed to precisely define the subset of exposures to transition risks.

To make the sectoral SyRB an effective tool in covering climate-related financial risks, a targeted revision of the EBA Guidelines would be desirable. In this context, EBA (2023b) has already indicated that it stands ready to support the revision of the EBA Guidelines on the appropriate subsets of exposures to which the competent authority or the designated authority may apply a systemic risk buffer. The European Systemic Risk Board (ESRB) could play a role in this revision to ensure that unintended consequences for the financing of the transition of current high emitters and unintended effects on adaptation financing are avoided when addressing transition

117 EBA (2020).

118 The four types of exposures are: (i) all retail exposures to natural persons which are secured by residential property; (ii) all exposures to legal persons which are secured by mortgages on commercial immovable property; (iii) all exposures to legal persons excluding those specified in point (ii); and (iv) all exposures to natural persons excluding those specified in point (i).

119 To identify the subset(s) of sectoral exposures, authorities must combine one element or sub-element from each of the following three dimensions: i) type of debtor or counterparty sector; ii) type of exposure; and iii) type of collateral. These dimensions may be complemented and further specified by correlated sub-dimensions, respectively: economic activity, risk profile, and geographical area.

and physical risks. Furthermore, potentially explicit provisions to allow for more granular sectoral and geographical definition could even be included directly in the CRD text, in a future revision.

A consistent use of macroprudential tools across Europe is key to avoid fragmentation, and notably the ESRB could provide guidance on the use of the sectoral systemic risk buffer against climate risk. This guidance could extend to suggestions regarding activation or calibration methodologies. This could be achieved through a revision of the ESRB handbook on operationalising macroprudential policy in the banking sector or, if a revision is not planned in the near future, a separate guide to using macroprudential tools against systemic climate risks.

A common calibration methodology of a SyRB for climate risks

Available experiences suggest that the calibration of the SyRB can be based on a number of different methodologies. For example, average losses and the associated levels of capital depletion can be considered. In the case of Lithuania, the supervisory authorities looked at banks' credit losses on mortgage loans based on risk-weighted mortgage exposures. Alternatively, maximum expected losses can be used to calibrate the level of the SyRB. In Slovenia, the authorities ran simulations under the most conservative assumptions to calibrate their sectoral SyRB (sSyRB). In an indicator-based approach setting, the final calibration could be based on a "Bank capital-at-risk" (Lang and Forletta 2020), akin to the concept of "Growth-at-risk", whereby current risk indicators inform future downside risks to bank profits. The sSyRB is then set so that the capital buffer is able to absorb losses in tail events.

The stress testing approach is widely used to inform the calibration of the general SyRB and to obtain an estimate of the credit losses that banks portfolios would likely sustain in a period of high financial stress. The level of the SyRB is then calibrated to ensure that banks are better able to absorb these potential losses. To date, calibration approaches for the sectoral SyRB applied to real estate exposures have relied heavily on the use of stress testing. The percentage of credit losses sustained by bank housing loan portfolios is based on stressed probability of default (PD) and LGD. This approach to calibrating the sectoral SyRB for RRE exposures is likely to be useful in the context of climate risks. Transition and physical risks are expected to be reflected in the credit risk of banking sector exposures through higher PD and LGD. The stressed PD and LGD of banks' exposures under the different transition scenarios can be used to assess losses resulting from the materialisation of climate risk. The associated level of capital depletion needed to absorb these losses could provide a basis for discussion on the calibration of the SyRB for climate risks, in both its general and sectoral versions. At the same time, the use of stress tests to calibrate the SyRB gives rise to challenges, notably in relation to the risk of potential overlaps which may arise with Pillar 2 guidance that is also based on stress test results. Close coordination between macroprudential and microprudential authorities would be essential to avoid any such overlap.

For climate risks, a stress testing approach appears to be the most suitable for calibration purposes. Stress testing appears to be a more appropriate approach to reflect climate risks in the calibration of the SyRB, as recent climate stress testing initiatives map broader physical and transition risks to the credit risk of banking sector exposures. This allows for a direct assessment of the potential impact of the materialisation of climate risks on bank losses based on forward-looking scenarios. An indicator-based approach, similar to the CCyB framework, could be considered, but would face significant challenges. Indeed, the use of climate risk indicators to calibrate the SyRB should ideally be based on an empirical link between the accumulation of climate risks and periods of financial distress. Although the development of climate risk indicators has accelerated recently, assessing their early warning properties could prove exceedingly difficult. This complication arises from the challenge of identifying periods of climate risk materialisation from historical data. In contrast, the stress testing approach overcomes this issue by relying on scenario analysis instead of historical data on climate risk materialisation.

A key consideration when calibrating the SyRB is the selection of the relevant climate scenario under which bank losses are to be assessed. Here we can distinguish between long-term and short-term scenarios. Long-term scenarios typically have a time horizon of between 10 and 30 years and are useful for assessing trade-offs between more and less ambitious climate policies. Short-term scenarios have a horizon of one to five years and allow for the assessment of one-off adverse events, such as periods of significant increases in carbon prices or acute flooding. A comprehensive risk assessment should take advantage of the complementary nature of long-term and short-term scenarios: while the former tend to smooth out short-term fluctuations and focus on long-term trends, the latter are able to illustrate the financial stability implications of deviations from these trends caused by short-term developments. Given that the time horizon relevant for the definition of capital buffers is more aligned with short-term scenarios, these are likely to be more relevant for the calibration of a climate SyRB. Short-term scenarios offer greater flexibility as they allow for the modelling of specific climate policies or events. They are also more closely aligned with traditional stress testing and therefore easier to integrate into banks' capital adequacy assessments. When calibrating the SyRB, it is important to explore different severities and manifestations of climate risk. Given the uncertainties surrounding climate risks, it is crucial to weigh up the pros and cons of relying on just one scenario when calibrating the buffer as opposed to basing the calibration on a range of scenario results.

To properly calibrate a SyRB it is key that the climate stress test identifies the impacts of climate-related risks in the real economy and how they spill over into the financial sector, including systemic amplifiers. Climate stress tests allow for the assessment of credit and market risks for an extended set of non-financial institutions – including not only corporates but also households and governments – under short-term scenarios. The resulting PD and LGD values, which reflect the materialisation of climate risks, can serve as valuable inputs when calibrating a SyRB to address climate risk. Adjusting the climate stress scenarios to better account for additional channels that amplify and propagate the effects of climate shocks is especially important to capture the systemic component of climate risks. In particular, the materialisation of climate risk under an adverse macroeconomic scenario may lead to compounding effects as feedback loops intensify bank losses. Incorporating compounding risks into scenario analysis allows macroprudential authorities to better understand and estimate the full scope of transition and physical risks.

Box 4

An illustrative calibration exercise of a climate systemic risk buffer based on the ECB climate stress test

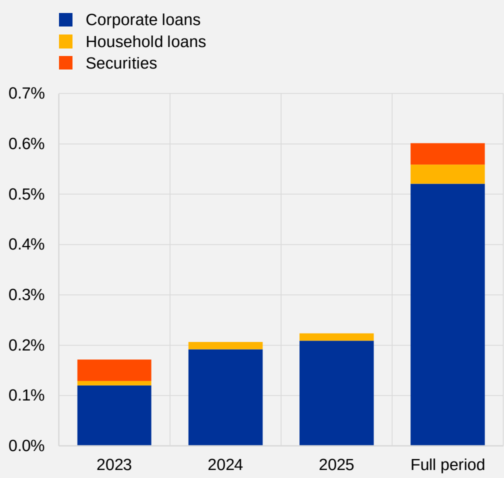
This box presents an illustrative application of the climate SyRB calibration methodology, focusing on transition risk in the euro area banking sector. We start from the current policies scenario and the accelerated transition risk scenario in the second ECB top-down economy-wide climate stress test (CST) (Emambakhsh et al., 2023). Based on the evolution of key variables (energy prices, energy mix, green investments, etc.) in both scenarios, the ECB CST projects probabilities of default (PD) for corporates and households. Using these PDs, we estimate future losses on corporate loan, household loan and corporate securities portfolios for 107 euro area significant institutions.

Chart A

Projected transition risk losses

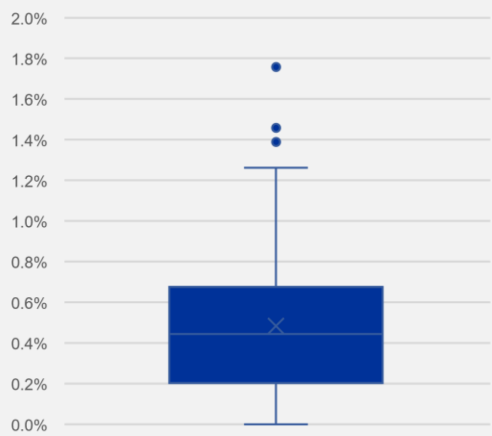
a) Aggregate losses

(y-axis: percentage of RWAs)



b) Bank-specific losses

(y-axis: percentage of RWAs)



To calibrate the climate SyRB, we isolate unexpected transition risk losses, on the assumption that banks have already adequately provisioned for the expected transition risk component. Since the current policies scenario captures the expected transition pathway, we can subtract the losses under this scenario from the losses sustained under the transition risk scenario to isolate this component. Moreover, since both scenarios are built on the same baseline macroeconomic scenario, this approach allows us to calculate the future unexpected (and hence not provisioned) losses that can be attributed purely to climate transition risk. Subsequently, these projected transition risk losses, expressed as a percentage of risk-weighted assets (RWAs), are mapped into different buckets to translate banks' transition risk losses into a bank-specific climate SyRB (with steps of 50 bps). In line with the calibration of Pillar 2 guidance, transition risk losses are then multiplied by a CF to scale down losses before mapping them into different SyRB buckets. The choice of the calibration factor entails a trade-off between higher resilience against unexpected transition risk losses and the possible cost of the required capital increase. Following a similar approach as for the RRE SyRB, we use a three-year period (2023-2025) for our calibration exercise.

Over the three-year period, aggregate transition risk losses are projected to reach 0.60% of RWAs (or €52 billion), with most losses originating from banks' corporate loan portfolios (Chart A, panel a). Notably, the estimated losses may represent a low estimate of future climate-related losses due to both the focus on transition risks and some important systemic amplifiers (e.g. tipping points) not yet accounted for. Our results reveal a high degree of heterogeneity across banks: while median bank losses are below 0.50% of RWAs, a handful of banks have projected losses well above 1% over the 2023-2025 period (Chart A, panel b). The resulting climate SyRB distribution is shown in Table A. Using a CF of 1, most banks receive a SyRB requirement of 0 bps (33 banks) or 50 bps (56 banks), and only 18 banks are assigned a SyRB of 100 bps or more. On aggregate, this SyRB would require €51 billion of additional capital. Lower calibration factors imply a lower SyRB for most institutions and a lower amount of aggregate capital raised (€29 billion with a CF of 0.5 and €1.5 billion with a CF of 0.25).

Table A

Illustrative climate SyRB with different calibration factors

Transition risk losses	Climate SyRB	Number of banks		
		CF=1	CF=0.5	CF=0.25
< 0.25%	0 bps	33	65	96
[0.25%, 0.75%]	50 bps	56	40	11
[0.75%, 1.25%]	100 bps	13	2	0
[1.25%, 1.75%]	150 bps	3	0	0
>= 1.75%	200 bps	2	0	0

Source: Simoens et al. (2023).

Additional considerations

The strategy for calibrating the SyRB should align the banking system overall capital buffer requirement with the potential losses resulting from the materialisation of climate risks. Banks should hold an appropriate level of capital to cover losses associated with serious disruptions in the economy or the financial system caused by the materialisation of climate risk. This increases bank resilience and ensures their ability to continue supplying credit to the real economy, even after loss absorption. By considering the systemic dimension of climate risks that can arise from interactions within the financial system, the SyRB is able to complement microprudential measures, which focus on the risks faced by individual banks.

Avoiding overlaps with other capital buffers is crucial to avoid double counting of risk coverage when calibrating the SyRB for climate risk. The level of the SyRB is set by deducting, from the level of simulated losses, existing macroprudential buffers that may already cover climate risks to some extent. In particular, overlaps with the capital conservation buffer (CCoB) should be carefully considered, as this buffer is designed to absorb unexpected losses arising from an adverse scenario. Therefore, when calibrating a SyRB for climate risks, Member States should consider the availability of the CCoB to absorb losses resulting from the materialisation of climate risks. It is also prudent to assess the overlap with the Pillar 2 Guidance (P2G). Although it is not part of the combined buffer requirement, the P2G is a first line of defence (after the voluntary buffer) in covering losses. Given its flexibility, supervisors may consider the potential impact of climate risks on banks and may use climate stress testing or other appropriate scenario analysis to inform its calibration, leading to potential double-counting of risks. Overlaps with the CCyB and buffer for Globally Systemically Important Institutions (G-SII)/Other Systemically Important Institutions (G-SII/O-SII) are likely less relevant as the former targets cyclical risk (instead of structural risk) while the latter aims to mitigate externalities arising from excessive risk-taking among systematically important institutions and the associated moral hazard (commonly referred to as "too big to fail").

To ensure the right balance between consistency across Member States and national flexibility in calibrating the SyRB for climate risk, national authorities should make efforts to build a strong communication strategy. This is important in order to clarify the nature of the risks that Member States are looking to address, particularly in terms of their timing and systemic nature, as well as the necessary conditions for an eventual release of the buffer. In addition, clear communication on the methodological framework for calibrating the buffer and on potential overlaps with other capital requirements is important to mitigate concerns about double-counting of climate risks.

4.2.1.3 Borrower-based measures (BBMs)

Climate risk can impact both borrower solvency and the value of (residential or commercial) real estate loan collateral[120]. In several climate transition scenarios, a considerable increase in energy prices penalises vulnerable households (or NFCs), which could lead to a higher probability of default (PD). This might be especially the case for debtors who live in less energy efficient properties. Climate risks could also directly affect the value of real estate assets – a significant portion of household wealth – thus increasing the value of LGD of housing loans. Property valuations might come under pressure due to the significant investment potentially needed in order to align energy efficiency with general regulatory or market expectations, or to adapt to a greater exposure to physical risks in areas more exposed to natural hazards such as flooding. The latter may push up insurance costs for borrowers, affecting, in turn, their disposable income. Early findings from the literature suggest that energy efficiency of real estate collateral is a significant determinant of credit risk to households: studies find evidence of – and a green premium linked to – energy efficiency as measured by energy performance certificates (EPC) (EBA 2022; EC-EEFIG 2022) and the findings also suggest that the energy efficiency of buildings – primarily residences though also their surrounding infrastructure – is positively associated with relatively lower

[120] This section refers to BBMs in a broad sense, covering both BBMs for residential real estate (RRE) and commercial real estate (CRE) loans, although the former are much more widespread than the latter. We do not cover the specific application of BBMs to NFCs in general, beyond the CRE sector, although the considerations presented in this section regarding BBMs for CRFRs could be relevant for NFC debtors as well.

probability of mortgage default (EC-EEFIG 2022; Billio et al. 2022).[121] Higher risk of physical damage due to natural phenomena related to climate change may also affect the market valuation of real estate assets.[122] Literature shows, for instance, that while climate-related catastrophes have a negative impact on house value, this effect is short-lived in locations where there is strong awareness of, and experience with, extreme weather-related events and that proactive public investment and strong governance as risk mitigating factors may be decisive in ensuring that such price reductions are relatively modest and short-lived[123]. However, climate risks are not yet properly assessed and managed by financial institutions and notably by banks, as highlighted by the results of the 2022 SSM thematic review on climate risk.[124]

BBMs are largely designed to prevent excessive overindebtedness and related real estate market imbalances. Therefore, they might also be used to mitigate particular climate-related financial risks. BBMs could, and to some extent already, mitigate vulnerabilities of climate-related physical and transition risks without purposely being devised to do so. Incorporating unaccounted climate risk factors into the calibration of BBMs could support a more effective assessment and management of overall risks to borrower solvency and collateral value, especially where sector-wide valuations do not seem to be sufficiently forward-looking.

The implementation of climate risk-related BBMs could be facilitated by ongoing efforts to bridge existing data gaps. Reflecting climate-related financial vulnerabilities in BBMs would require the data-driven characterisation of the related risks. This would in turn entail the collection and processing of data, which may fall outside the usual monitoring remit of regulators and lenders, complemented with new analytical capabilities. In a recent survey conducted among members of the Instruments Working Group of the Macroprudential Policy Group (IWG-MPPG), most of the respondents reported issues with data availability, including EPCs for mortgage collateral, or the share of and trend in non-renewable energy costs in borrowers' budgets.[125] Therefore, addressing these data gaps would be a natural first step in the design of BBMs to better account for climate risks.

Various EEA countries are currently analysing or looking to analyse the potential impacts of climate risk in relation to BBMs, though only a few adjustments to BBM frameworks based on climate-related characteristics have been reported so far, all designed as prudential relief

121 Regarding real estate markets, early findings from the literature suggest that energy efficiency of real estate collateral is a significant determinant of credit risk to households. A review of the literature indicates a positive relationship between the market value of residential owner-occupied, rental and commercial real estate and the energy efficiency of the dwelling. Studies find evidence of – and a green premium linked to – energy efficiency as measured by energy performance certificates (EPCs). Both EBA (2022) and EC-EEFIG (2022) refer to a 5-10% premium when comparing high and low energy performance real estate. Several studies find that energy efficiency is negatively related to a borrower's likelihood of defaulting on mortgage payments (EC-EEFIG, 2022; Billio et al., 2022). However, these studies faced certain limitations, including the variability of the available data used (e.g. differing EPC definitions), and the lack of a comprehensive set of control variables (i.e. variables correlated with the mortgagor's choice of a more energy-efficient building).

122 For example, Perez-Quiros et al. (2022) find that a publicly perceived extreme environmental disaster in a coastal area of Spain caused a 43% reduction in the return on housing investments. The indicative calculations of Kauko et al. (2021) estimate €150-350 million of at risk housing loans for residential dwellings located in Finnish coastal flood risk areas and €100 million at risk in commercial real estate collateral.

123 See Clayton, J. et al. (2021).

124 See ECB (2022b).

125 The importance of the accessibility of EPC data, for instance in a transparent register in each Member State, was also highlighted by the EC-EEFIG (2022) working group. Ongoing regulatory initiatives, such as the review of the Energy Performance of Buildings Directive (EPBD), are expected to significantly improve access to EPCs among lenders and supervisors.

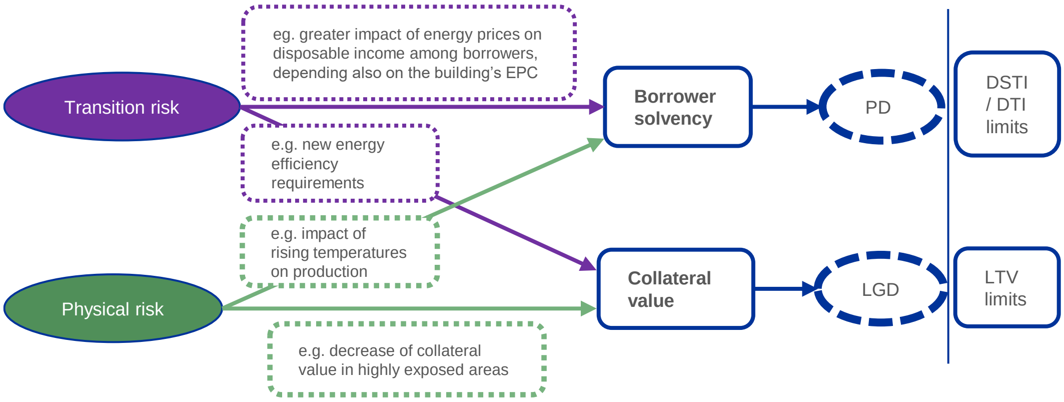
(e.g. looser limits) for lending to improve levels of energy efficiency. Two Member States, Slovakia and the Netherlands, adjusted the measures to take into account the improved risk profile of lending secured by energy-efficient immovable property, although CRFRs are not cited as the main cause of the adjustments.[126] In Latvia, BBM measures have not been applied for credit loans granted to modernise blocks of flats. In Estonia, the loan to value (LTV) limits are slightly higher for state-backed housing loans, which are largely intended for borrowers who purchase energy-efficient housing or who renovate their home to improve its energy performance.[127] Elsewhere, France and Portugal apply marginal maturity limit modifications to facilitate the uptake of specific types of loans related to fiscal support programmes for housing renovation and which imply a delayed use of the property, although these modifications were not designed on the basis of climate risk considerations. Lastly, some Member States indicated that they are looking to introduce adjustments in their BBM framework to account for CRFRs.

Design of BBMs addressing climate risks

Current borrower-based frameworks, including calibration methodologies, do not yet fully account for potential climate risk--related financial vulnerabilities. PD and LGD can be influenced by factors related to climate risks such as geographical location, energy efficiency of the loan collateral, or inadequate insurance coverage against physical risk (Figure 13). In this context, the calibration of existing BBMs may underestimate or overestimate climate risks.

Figure 13

Transmission channels of climate risk to BBMs



Source: ECB/ESRB.

[126] In Slovakia the DSTI limit and maturity limit have been eased for loans co-financing home renovations from EU Recovery and Resilience Facility: the maximum instalment implied under the current DSTI limit (60%) may be increased by €50, and the maximum maturity extended from eight to ten years. In the Netherlands, pre-defined sums can be deducted from the loan amount for the purposes of assessing the payment to income (PTI) situation of the debtor when purchasing a home with high energy efficiency. Also, the lender may deviate moderately from the maximum loan amount for the LTV calculation in the case of flats with extraordinary energy efficiency ratings. Beyond the specific modifications presented so far, regulatory design can also implicitly differentiate the treatment of energy-efficient housing.

[127] For more information on the Estonian BBM measures, see **https://www.riigiteataja.ee/en/eli/528082015002/consolide**. For more information on KredEx housing loan guarantees, see **Housing loan guarantee | KredEx.**

Accounting for climate risks when calibrating BBMs might be a first step to adjust the limits in countries where climate risks are considered systemically relevant or as increasing absolute risks. The different impacts of climate risk on borrower solvency and collateral value could be accounted for in the models used to calibrate BBM limits and in the input components used to calculate the BBM ratios. For instance, the potential impacts of transition risks could be reflected in the income or income stress tests used to calculate debt to income (DTI) or debt service to income (DSTI), while physical risks affecting the valuation of the property could be included in LGD modelling. This may result in adjustments to existing BBM limits without changing the actual design of the existing framework.

BBMs might also be differentiated for loans heavily exposed to, or protected from, climate risk to limit the build-up of previously identified pockets of climate risk. In this case, the differentiation of BBMs could be designed to reflect an increase in relative risks, that is to say the varying levels of climate risks associated with different housing options. For example, loans for energy-efficient houses, part of which might be aligned with sustainability policy goals and benefit from governmental support programmes aimed at risk reduction as well, could be subject to a relatively lower BBM limit. Conversely, loans for low energy-efficient housing and higher associated risks would have to comply with relatively tighter limits. Climate risk indicators, such as the share of loans with collateral located in high-risk areas or the share of borrowers vulnerable to transition risk, could be considered for the activation or modification of BBMs. The introduction of differentiated BBM limits would require evidence of risk differentials linked to exposure to non-sustainable real estate or activities, and justification that these risks are not already accounted for in the current BBM calibration. Table 5 below provides a synthetic overview of potential design options for BBMs based on climate-related risk measures.

Table 5

Overview of potential design options based on CRFR measures

	Adjusting inputs to BBM calibration without introducing differentiated limits	Introducing differentiated limits based on CRFR characteristics and measures	
		Risk-neutral adjustment	
		General	Supporting fiscal programs
Description	Incorporating CRFR in the risk assessment and calibration.	Applying relatively looser limits for climate risk-resilient lending and relatively tighter limits for lending sensitive to climate-related risk.	Applying looser limits for climate risk-resilient lending associated with fiscal programmes to enhance sustainability.
Evaluation	A simple, long-term approach complementing existing risk assessment and calibration with climate risks.	Risk sensitive differentiation of the limits. Possible if climate risk is assessed as systemically relevant.	A risk sensitive differentiation limited to a well-defined fiscal programme supporting sustainable lending may be limited to a marginal volume of credit.

Source: ECB/ESRB.

Even if climate risk is not assessed to be systemically relevant, it may be desirable to consider exceptions to BBM limits for loans that are based on environmental government support programmes. The exemptions or beneficial treatments could be applied to loans that benefit from government programmes there to promote environmental objectives, such as energy efficiency. The aim of implementing these exceptions is to ensure that existing limits do not become overly stringent for projects that receive fiscal support or incentives. Consequently, the exceptions would not have a significant effect on systemic risks and would, in many cases, apply only to a marginal share of total loans, without affecting banks' loan portfolio allocation.

Activation and calibration methodologies

To limit the build-up of climate risks, a set of CRFR indicators focusing on both households and NFCs could be implemented to activate BBMs, depending on the data gaps remaining. Starting from the three indicator categories often used in Europe, Table A.2 in Annex 3 – Lessons from use of SyRB for systemic risks presents a non-exhaustive list focusing on climate indicators. In the first category (real estate overvaluation), climate indicators are based on overvaluation models and on the effects of transition and physical risks on collateral values, price-to-income ratios and risk premium. In the second category (borrower debt servicing capacity), the CRFR indicators focus on emissions, energy expenses and energy efficiency of real estate assets. In the third category (observed distribution of DSTI, DTI and LTV), climate indicators serve as early warnings to spot and flag the most financially constrained borrowers. Data limitation currently represents a constraint when, for instance, a high level of granularity is required or where it is difficult to connect climate and financial information.[128]

There is significant heterogeneity in the calibration approaches and methods used for BBMs among EU authorities. Despite the growing number of implementations, which now extend to 25 jurisdictions across the EEA, and the fact that more extensive empirical work is now available on ex post impact studies, there is still no broadly applicable modelling framework for ex ante calibration, due largely to the different structural characteristics of the mortgage markets in each country and differing levels of judgement and risk tolerance among policymakers (Hejlová et al., 2021).[129]

Upon identifying the associated climate risks, extensions of the various BBM calibration approaches might be developed to account for them. If recalibrating the DSTI limits is considered justified, macroprudential authorities may consider integrating, into their quantitative analyses and models, the expected impact of transition and physical risks on the debt servicing capacity of borrowers, such as increases in necessary living expenses related to energy consumption, expenditures on energy retrofitting, costs of renovating living spaces affected by natural disasters, or investments to adapt to physical risks. Empirical evidence on the exposure of

[128] New reporting requirements for banks, regulatory initiatives (such as the ongoing revision of the EPBD) to improve access to EPCs, or methodologies based on an estimation of missing variables (such as energy certificates), could help solve this connection issue.

[129] A tentative categorisation of calibration approaches and techniques might include: (i) relying on risk indicators and monitoring statistics, such as distribution of lending standards; (ii) micro-models of borrower PD (see, for instance, Gross and Población, 2017, developed further by Jurka, 2020, Barasińska et al., 2021, and Giannoulakis et al., 2023; (iii) semi-structural micro-macro modelling framework suitable for simulations (see, for instance, Bank of Ireland, 2022, and Box 4 therein); and (iv) complex partial equilibrium, dynamic stochastic general equilibrium (DSGE) and agent-based models (see Laliotis et al., 2020, and Catapano et al., 2021).

borrowers to climate risks is key to guide the calibration of DSTI limits.[130] Similarly, determining the level of collateralisation for the LTV limits might also include potential damage caused by the materialisation of physical risks, or the expected impact of the green transition process on valuation, including the introduction and gradual tightening of national minimum energy efficiency/performance standards for residential properties and the revised Energy Performance of Buildings Directive (EPBD).

Survey results indicate some progress in incorporating climate risks in BBM calibration methodologies. While the work is at an early stage, a number of Member States have reported that they are currently developing tools to assess the impact of CRFRs.[131] So far, only a couple of stress scenario analyses can be taken as helpful building blocks for integrating climate risks into the calibration framework. For example, Caloia et al. (2021) provide an example how to estimate the long-run financing needs of households looking to retrofit their homes. Regarding the preferred techniques, forward-looking scenario analysis appears to be the most promising tool to be adapted, based on the findings of the IWG-MPPG survey.

Cost-benefit analysis

As part of the macroprudential response, BBMs may complement other instruments in mitigating excessive CRFR build-up in specific credit segments, primarily RRE lending. Limiting the excessive outflow of credit to borrowers vulnerable to climate risk might improve their debt servicing capacity and reduce losses for the lender. It might also ensure wider access to housing retrofitting and renovation work, in conjunction with public programmes, which in turn could reduce the concentration of loan portfolios towards collateral highly exposed to climate risks. In general, tightening BBMs affect only the high-risk tail of the distribution of new loan outflow. At targeted market segments, they may nonetheless complement capital buffers to cover both stocks and outflows.

Design and calibration choices might depend on expected future policy developments. First, changing prudential requirements may render existing limits more effective to mitigate CRFRs without the need for any further adjustment. For instance, the Capital Requirements Regulation (CRR) III proposal clarifies that modifications made to a property that improve the energy efficiency of the building or housing unit must be considered as unequivocally increasing its value. LTV regulations based on such collateral valuations would already account for upward adjustments of energy efficiency, at least in part. Potential adjustments should also avoid double-counting of risks, where ongoing or future legislative processes, supervisory guidance or observable market practices already address such matters. Second, EU and national public policies setting targets for building

[130] Banco de Portugal (2022) shows that low-income households are more vulnerable to energy price increases as energy expenses tend to consume a higher proportion of their income. Faiella, Lavecchia, Michelangeli and Mistretta (2022) evaluate the introduction of a carbon tax and conclude that a moderately sized tax does not lead to a sizeable increase in the share of financially vulnerable households. Several studies (see, for example, Billio, Costola, Pelizzon and Riedel, 2022, or Guin and Korhonen, 2018) suggest that higher housing energy efficiency is associated with lower probabilities of default.

[131] In particular, five Member States responded they are quantitatively exploring the default risk implications of climate risk or energy performance and costs, and nine of the answers received alluded to the exploration of real estate collateral valuation affected by climate risks. A couple of other Member States noted that work was ongoing, though without providing further details.

renovation and decarbonisation (such as the EPBD) may affect underlying transition risks and the expected efficiency of climate risk-related BBM adjustments. Due to these considerations, we need to be wary of microprudential and fiscal policies when designing BBMs targeted at CRFRs.

Any attempt to modify BBMs to target CRFRs should not jeopardise systemic risk objectives, nor disproportionately restrict housing loan availability. If the adoption of a BBM design conducive to sustainability-improving lending does not lead to an expected reduction in risk through collateral valuation, household cost savings or other reasonable channels, then this circumstance could hinder the achievement of macroprudential risk objectives. A BBM design excessively lenient towards large-scale climate-related fiscal support programmes might even lead to an increase in portfolio concentration via its relaxation of lending standards. The adoption and implementation of BBMs based on national legislation could be tailored to country-specific transition pathways or geographic variation of physical risks. However, cross-country differences could also trigger fragmentation in country-specific responses.[132] Beyond financial stability considerations, concerns over a possibly restriction of household financing – generally relating to the unintended socio-economic impacts and side effects of BBMs – may arise as well due to the regulatory changes introduced to account for CRFRs. [133]

4.2.2 Policy considerations beyond the banking sector

Specific features of non-bank financial entities and markets can contribute to the build-up and materialisation of systemic climate risks and appropriate policies can help to reduce address the macroprudential challenge of climate risks in these sectors. 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. Challenges to insurability can acquire systemic relevance if not properly managed, with potentially significant spillovers. Investment funds and markets have been at the forefront of efforts to mobilise finance for the green transition, but, in the absence of clear standards, they are exposed to greenwashing risk, and can amplify climate risks through traditional liquidity risk channels.

4.2.2.1 Policies in the insurance sector

Addressing the insurance protection gap

Catastrophe insurance is a key tool to mitigate macroeconomic losses following extreme climate-related events, as it provides prompt funding for reconstruction and should incentivise risk

---

[132] This could be addressed by defining a set of common principles on how to apply BBMs across the EEA, as recommended by the ESRB in its advice on the review of macroprudential policy (see ESRB, 2022).

[133] For instance, stricter limits for low-quality real estate collateral could exacerbate credit constraints among borrowers already struggling with housing affordability. Low-income borrowers may face credit constraints, besides other informational problems and behavioural impediments, thus making it harder for them to finance energy efficiency-improving investments and creating the so-called energy efficiency gap, which occurs where the consumer misses out on the present value benefits of energy efficiency if the purchase involves relatively high upfront costs. See, for example, Eryzhenskiy et al. (2022).

reduction and adaptation.[134] The overall societal cost of a disaster depends not only on the severity of the initial damage but also on how swiftly reconstruction can be completed. However, reconstruction can be prolonged, and may even be incomplete, in the absence of sufficient resources. Insurance payouts reduce uncertainty and support aggregate demand and investment for reconstruction, enabling economies to recover faster and limiting the period of lower output.

If managed properly, insurance can further mitigate systemic risk for financial institutions and financial markets by, for example, transferring collateral or property losses, as well as promoting adaptation to limit future losses from catastrophes. Natural disasters can be a source of systemic risk for financial institutions and financial markets, most notably through the physical damage they cause to assets or supply chain disruptions. In both cases, a high concentration of key economic activities in high-risk areas can amplify such losses, giving local events wider significance. This can result in a lower provision of credit in high-risk areas and to lower income borrowers, thereby hindering adaptation efforts in the areas most in need. Lack of insurance may also prevent some property from qualifying as eligible collateral, potentially increasing the exposure of banks to credit risk. This insurance-banks feedback loop can further amplify vulnerabilities to physical risk in certain areas.

Only about a quarter of climate-related catastrophe losses are currently insured in the EU. This insurance protection gap could widen in the medium to long term as a result of climate change, partly because repricing of insurance contracts in response to increasingly frequent and intense events may lead to such insurance becoming unaffordable. This would further increase the burden on governments, in terms of both macroeconomic risks and the fiscal spending needed to cover uninsured losses, and may also pose financial stability risks.

Possible actions which could be considered to address the protection gap and mitigate catastrophe risks from climate change in the EU by means of insurance coverage and adaptation measures should fulfil the following main objectives:[135] help provide prompt insurance claim payouts following a natural disaster; incentivise risk mitigation and adaptation measures; be complementary to existing insurance coverage mechanisms; require the sharing of costs and responsibilities across the relevant stakeholders to ensure "skin in the game" and reduce moral hazard; and lower the share of economic losses from major natural disasters borne by the public sector over the long term.

The proposed actions follow a "ladder approach", reflecting the share of losses from natural disasters borne by various parties at different loss layers. It builds on the existing frameworks of private insurance and public sector intervention, and discusses the case for a certain degree of coordination of public sector efforts at the EU level (Figure 14). Private (re)insurance should be the first line of defence to cover losses from climate-related natural disasters. Financial markets may also be used to transfer risks via catastrophe bonds (CAT bonds) and thus support the reinsurance of such risks.

Building on existing frameworks of private insurance and public sector intervention, a "ladder approach" of policy responses may be considered. The approach indicates the share

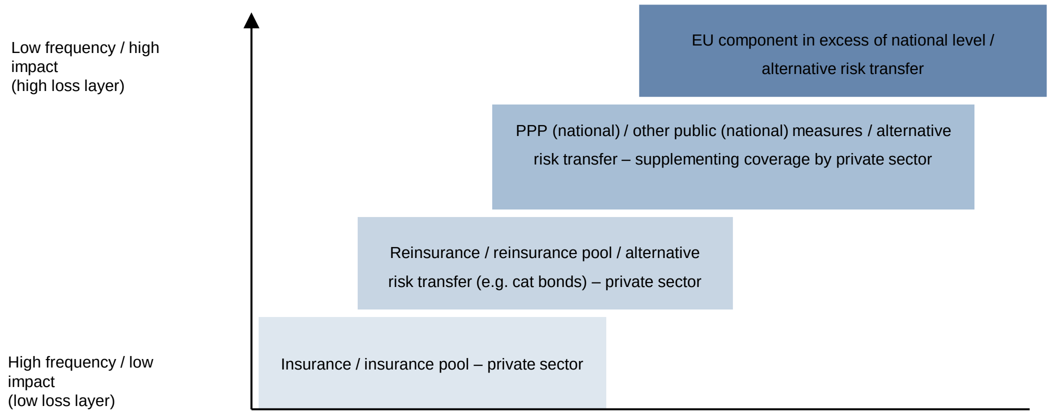
[134] See Fache Rousová et al. (2021).

[135] ***Staff Paper on Policy options to reduce the climate insurance protection gap*, EIOPA, 2023.**

of losses from natural disasters borne by various parties at different loss layers. Private (re)insurance should be the first line of defence to cover losses from climate-related natural disasters. The use of financial markets to transfer risks via catastrophe bonds (cat bonds) may also support the reinsurance of such risks. To address residual limits to insurability, public sector solutions in accordance with national circumstances may be needed, including public-private partnerships (PPPs) and ex ante public backstops – which could be reinforced by coordination efforts at the EU level (Figure 14).

Figure 14

A ladder approach to catastrophe insurance



Source: ECB-EIOPA (2023).

While higher private insurance coverage is beneficial and desirable, insurance provision should be carefully designed to ensure that it encourages adaptation and reduces vulnerability to climate-related catastrophes over time. Insurers should provide incentives for risk reduction and adaptation by, for example, promoting risk awareness and providing risk-based incentives linked to premiums (e.g. via impact underwriting). Such measures would directly reduce preventable damages from catastrophes and increase resilience, while also supporting insurability and helping to limit the risk of a widening insurance protection gap.

A pilot study among European insurers on impact underwriting practices indicates that climate-related adaptation measures in non-life underwriting are still at an early stage.[136] The use of adaptation measures currently appears to be better suited for commercial insurance products due to the typically individualised risk assessments and insurance contracts used in that segment, compared to the more standardised retail business. Furthermore, the take-up of climate-related adaptation measures is only rarely incentivised through premium discounts, largely due to difficulties in assessing the precise impact of these measures on risk exposures. Improvements in standardising adaptation measures and underwriting practices (e.g. in terms of common risk assessment programmes or risk labels) could help to foster a more widespread implementation of adaptation measures and provide risk-based incentives for policyholders through premium

136 ***Impact underwriting: Report on the Implementation of Climate-Related Adaptation Measures in Non-Life Underwriting Practices*, EIOPA, 2023.**

reductions, as could the development and enforcement of public building codes adapted to the dynamics of climate change.[137] Behavioural traits, information availability and the way insurance is sold significantly influence consumer demand for insurance. A lack of awareness among policyholders about climate change and related adaptation measures is a key factor influencing levels of demand for the corresponding insurance products.

By supporting primary insurers, reinsurance plays a key role in managing risk from low-frequency, substantial-impact events, but might reach its limit with climate change. An increased frequency and/or correlation of extreme events causing substantial economic damage might prompt reinsurers to either charge very high premiums or stop underwriting catastrophe risks altogether. This would have a knock-on effect on primary insurers and policyholders, who would either have to pay a very high premium or bear the risk themselves (retention).

If climate-related risks are not insured by the private sector to a sufficient degree, public sector intervention may become necessary, perhaps in the form of PPPs, in accordance with national frameworks.[138] PPPs are insurance schemes that provide government financial support to supplement the losses insured by the private sector. They can support the overall functioning of the insurance market by providing additional coverage, either via direct insurance or by indemnifying a private (re)insurer against extraordinary events. Mandatory insurance coverage is often a key element of PPPs, but entails certain trade-offs. It can help to improve insurability in high-risk areas via mutualisation. Limiting the scope of coverage may lead to the very gaps that such a scheme aims to address. Furthermore, mandatory insurance schemes supported by the public sector may turn out to be regressive and end up subsidising development in hazardous locations and increasing residual risk. In addition, without appropriate safeguards, improved affordability of catastrophe insurance may disincentivise risk reduction and adaptation measures.[139]

PPPs should do more than just provide a financial backstop. They should also enhance risk assessment and awareness and/or promote risk reduction through adaptation measures, among other mechanisms. The design of PPPs should incorporate the four elements of a shared resilience solution: (i) risk assessment, (ii) risk prevention, (iii) product design and (iv) risk transfer (Figure 15). This implies that certain steps should be considered before deciding on the specifics of risk-sharing arrangements. First and foremost, we must have a sound understanding of the underlying risks, for instance via enhanced sharing of information on catastrophe risk modelling. Second, proactive measures for risk mitigation and adaptation should be preconditions for public sector involvement. Third, the insurance products should be designed in a manner that is easy for the policyholder to understand and provide the appropriate coverage at an affordable premium.

---

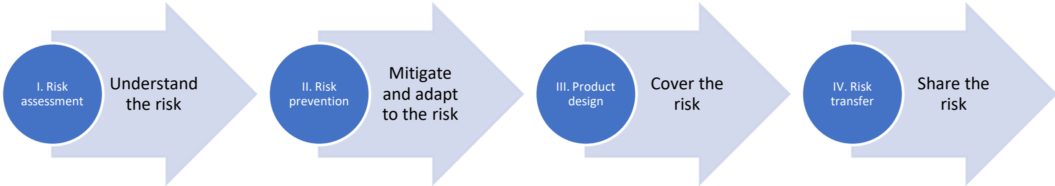
[137] Similar approaches exist in the US insurance market, such as under the FORTIFIED programme of the Insurance Institute for Business and Home Safety (IBHS), which provides recommendations on climate-related risk prevention measures related to wind, hail and wildfire risks. Further, the National Flood Insurance Program (NFIP) offers lower premiums when flood mitigation measures are in place.

[138] PPPs are already in place in some European countries to manage particular disaster risks. For instance, Caisse Centrale de Réassurance (CCR) in France provides reinsurance for natural disaster-related risks. The coverage must be included in all property insurance policies and eligibility is tied to private property insurance. Similarly, Consorcio de Compensación de Seguros (CCS) in Spain provides cover for catastrophe risks which is mandatorily linked to the valid taking out of an insurance policy (typically from private insurers) in certain lines of business.

[139] For example, the National Flood Insurance Program (NFIP) in the United States requires properties in high-risk flood areas to have flood insurance for mortgages from government-backed lenders. Until 2021 the NFIP charged the same amount for insurance, regardless of the value of the property and the share already insured privately. The Federal Emergency Management Agency (FEMA) then adjusted this mechanism to ensure that insurance prices reflected risks at the individual building level, thereby strengthening incentives for risk reduction.

Finally, limiting public reinsurance to the absolutely necessary, would be key to reduce fiscal risks of national PPPs, while also ensuring an accurate pricing of risks, promoting an efficient allocation of funds.

Figure 15
Elements of a shared resilience solution



Source: ECB-EIOPA (2023).

Capital market instruments, such as CAT bonds, can support traditional reinsurance and complement both private insurance schemes and PPPs for residual risks. They provide two key benefits: (i) diversification in the form of an alternative source of capital and (ii) a lower premium for overall coverage. Furthermore, CAT bonds could potentially combine impact underwriting with impact investing, as some World Bank issuances have shown. However, the issuance cost of CAT bonds in Europe can be significant, which is an area where public incentives, perhaps in the form of grants, might help. The public sector might also issue CAT bonds directly[140], for example through national PPPs, or through pooling residual risks from multiple national PPPs.

For less frequent, large-scale disasters, an EU-wide public scheme for natural disaster insurance covering a broad range of weakly correlated hazards could be effective in complementing national schemes. Pooling risks at the EU level could help to reduce the economic costs of catastrophes and accelerate recovery and reconstruction efforts, while incentivising and promoting ex ante risk reduction via both mitigation and adaptation measures. Any EU-wide fund should be additional to existing funding for tackling climate change, and should have safeguards to address moral hazard, such as making access conditional on Member States implementing agreed adaptation strategies and meeting their emission reduction targets. Such a fund would complement the EU's climate policies and related initiatives, such as the renewed sustainable finance strategy, and leverage on the experience from existing tools for disaster relief that are not currently able to respond to the increasing needs related to climate change, such as the EU Solidarity Fund (EUSF).

Addressing the impacts of climate-related risks on insurers' assets and liabilities

The treatment of climate-related risks is one of the central points proposed in the review of Solvency II, especially targeting insurers' risk management of these risks. The amended regulation sets out a framework for climate change scenario analyses to be carried out by

140 A prominent example is the California Earthquake Authority (CEA), a local state agency that underwrites residential earthquake risks in the United States.

undertakings as part of their own risk and solvency assessment (ORSA). Insurers should first assess the materiality of exposures to CRFRs and then carry out at least two long-term scenarios (global increase in temperature (1) below 2 °C and (2) equal to or higher than 2 °C). As the solvency capital requirement is calibrated with a one-year horizon, the analyses carried out under the ORSA will also include a forward-looking element and address risks that might materialise or make insurers more vulnerable over a longer term.

The process of exploring a dedicated prudential treatment for climate risks among insurers is still in its early stages. The draft Solvency II review also seeks to explore a potential dedicated prudential treatment of sustainability risks. EIOPA has, as a first step, published for discussion a methodology for the potential prudential treatment of notably transition risk exposures in asset holdings, as well as climate change adaptation in underwriting. [141] On transition risk, the methodology assesses the potential for a dedicated treatment of relevant exposures identified via (sectoral average) transition risk differentials in the market risk module. For the treatment of liabilities, the inclusion of climate change adaptation in product design might warrant the reassessment of the premium risk module due to potential changes in claims volatility. However, this would require a certain degree of standardisation in adaptation measures, so as to ensure that their impact on claims volatility can be reliably assessed. Uncertainties regarding the identification of relevant exposures and how to calibrate the corresponding measures have yet to be addressed.

Due to the systemic importance of insurers in pooling and diversifying climate risks, regulatory steps to increase their resilience to climate risks is key to preserving financial stability. As outlined in the previous section, insurers have systemic importance in pooling and diversifying climate risks and hence in mitigating the related financial risks. Increased losses due to natural events might lead to price increases, rendering insurance unaffordable, or prompt insurers to stop offering coverage for certain perils and geographies. In severe scenarios, it might even threaten insurers' ability to meet their liabilities. This would have cascading effects well beyond the insurance sector: the contagion could lead to a sudden increase in direct losses due to physical risk across large segments of the economy and directly affect banks' balance sheets through downward revisions in the value of immovable collateral, which in turn could turn translate into fiscal risks if the public sector has to step in to halt the contagion. As an EIOPA analysis[142] shows, even under a relatively mild warming scenario and a short-term climate horizon, changes in weather-related patterns are expected to have a cascading effect on the non-life insurance business. To ensure that insurers remain viable and to avoid contagion, close monitoring of known and emerging perils is vital. This can be achieved through further climate scenario analysis, through the proposed integration of climate change into the standard formula for calibrating and then regularly reassessing the natural catastrophe Solvency Capital Requirement (SCR)[143], and through increased transparency when modelling relevant data and catastrophe risk, such as via open source initiatives[144]. Yet, going forward, macroprudential approaches to address these aspects might be explored further, especially to reduce the vulnerabilities associated with the interconnectedness of insurance protection and banks' balance sheets.

---

[141] ***Discussion paper on the Prudential Treatment of Sustainability Risks*, EIOPA, 2022.**

[142] ***Financial Stability Report December 2022*, EIOPA.**

[143] ***Methodological paper on potential inclusion of climate change in the Nat Cat standard formula*, EIOPA, 2021.**

[144] ***Open-source tools for the modelling and management of climate change risks*, EIOPA.**

4.2.2.2 Greenwashing

Macroprudential relevance of greenwashing

From a prudential perspective, greenwashing[145] carries various financial risks, both directly and indirectly. Greenwashing can generally erode consumer confidence in sustainable finance products: should these risks materialise on a large, sudden and unforeseen scale, it could affect consumers' overall confidence in sustainable finance products and ESG markets, with the potential for significant and sudden sector-wide outflows from investment funds, redemptions from pensions funds and selling pressure in bond markets. Indirectly, actual greenwashing – or simply aversion to greenwashing risks – could diminish investment in sustainability if investors lose trust in the ability of the financial sector to finance the transition. More broadly, the misallocation of capital resulting from imperfect sustainability information negatively affects climate mitigation and may compound transition risks, by leading to involuntary carbon lock-ins and stranded assets. Overall, by hindering the ability of the financial system to support the transition to a sustainable economy in a timely fashion, greenwashing would contribute to the continued build-up of (systemic) climate risks.

Greenwashing risks can contribute to the spread of financial risk across the financial system, given the links between ESG funds and financial institutions. For example, the share of ESG funds managed by companies owned by euro area institutions has increased since 2020, both in total amount and as a share relative to non-ESG funds. While links between ESG funds and financial institutions can help optimise liquidity between the parent and affiliated institutions and provide long-term benefits in terms of revenue and risk diversification, they may also be a source of contagion during periods of stress: sudden outflows or market volatility associated with greenwashing risk might therefore spread and amplify vulnerabilities across the financial system. However, evidence shows that investor concerns over greenwashing have tended to centre on the financial risks associated with their equity holdings at the management companies rather than investor subscriptions and redemptions.[146]

EU supervisory authorities have found evidence of widespread greenwashing risks across the financial system, although the actual impact on financial stability remains unclear[147] (ESMA 2023a, ESMA 2023b, EBA 2023a and EIOPA, 2023). While further analysis on the impact is certainly needed, a macroprudential perspective that encompasses oversight of the entire system is warranted to ensure not only that individual firms are abiding by standards, but that consumers and the general public are also protected from any negative effects of greenwashing.

The quality and availability of harmonised disclosures needs to improve if we are to assess the macroprudential dimension of greenwashing risks. EU institutions have been pursuing a number of regulatory initiatives in recent years to improve public climate disclosures, and while the implementation process is still incipient, they will inevitably lead to improved disclosures over time.

---

[145] Greenwashing is a practice whereby sustainability-related statements, declarations, actions, or communications are not supported by clear evidence which shows how they are reflected in the underlying sustainability profile or mandate of an entity, financial product, or financial service. This practice may be misleading to consumers, investors, or other market participants.

[146] See ESMA (2023a).

[147] See ***ESAs present common understanding of greenwashing and warn on related risks***, 1 June 2023.

As things currently stand, the quality and consistency of sustainability disclosures falls short of what would be needed to satisfy market participants. For example, in the euro are banking sector, 45% of the banks' disclosures were assessed as insufficient in both content and substantiation perspectives.by ECB Banking Supervision.[148] In addition, until sustainability reporting rules are fully implemented, some financial firms may overemphasise their climate goals and credentials while continuing their relationships with polluting borrowers.[149] The entry into force of the EU's CSRD is expected to enhance the availability and comparability of climate disclosures, in turn supporting data availability on investee companies for asset managers, banks and insurers.

Considerable uncertainty remains over the real impact of sustainable investing, with a lack of clear standards and definitions increasing the risk of greenwashing. As shown in Section 2, the market share and price of green finance instruments have risen in recent years. Academic research has found that sustainable investors are willing to forgo returns in order to hold sustainable assets and therefore ESG ratings have meaningful effects on fund holdings and stock returns.[150] However, there is currently considerable uncertainty about the real impact of the sustainable investing industry[151]: existing research finds limited evidence to support the claim that ESG integration makes anything more than a marginal contribution to sustainability, thus highlighting the need for investors and policymakers to place greater emphasis on impact metrics that reflect the contribution to societal goals. Research also shows that green acquisitions by investing firms after the Paris Agreement do not appear to have any significant impact on their post-acquisition innovation performance, raising further concerns related to greenwashing behaviour among such firms.[152]

This uncertainty is compounded by a lack of transparency on the purpose of ESG ratings and the related sustainable investment strategies. Various approaches currently coexist in the market regarding the objectives and materiality approach underpinning ESG ratings.[153] Some ESG ratings aim to quantify an entity's actual ESG performance (i.e. impact materiality) in order to inform various types of sustainability-oriented investment strategies, while others aim to measure the potential impact of ESG factors on the risk-return of the investment, without having a direct connection to the actual sustainability of the underlying real activities (i.e. financial materiality). The coexistence of these different approaches, serving different investment strategies at the same time, creates confusion as to the purpose of ESG ratings, the degree to which they measure actual sustainability performance, and ultimately their ability to affect actual sustainability outcomes in the real economy. This can be a source of greenwashing, to the extent that ESG ratings might not match public expectations about the real sustainability impact of the financed investments. At the same time, financial stability may also be compromised if ESG ratings are unduly used as direct measures of financial creditworthiness.

[148] ECB Banking Supervision (2023).

[149] See Giannetti et al. (2023).

[150] See Heeb et al. (2023) and Berg et al. (2022).

[151] See Kölbel et al. (2020).

[152] See Bose et al. (2023).

[153] See Busch et al. (2021).

Policy considerations

The focus on greenwashing in the investment fund sector has increased as regulations kick in, and further fund classification efforts might prove useful in enhancing greenwashing surveillance. Since the introduction of the Sustainable Finance Disclosure Regulation (SFDR) disclosure regime, many funds have changed their SFDR status[154], which has raised concerns over the possible misuse of Article 9 status. ECB analysis[155] suggests that using a new classification system for green funds – based on which green strategy the fund is pursuing – would increase visibility on greenwashing risks.[156] This new categorisation would ensure a clearer understanding of a fund's carbon footprint and the related greenwashing risk. A new labelling system developed at EU level, or changes to the current EU regulatory framework to create distinct investment product labels or categories based on minimum standards, could help to address the risk of greenwashing and enhance greenwashing surveillance. In this context, the recent public consultation launched by the European Commission to explore potential changes to SFDR disclosures is an important window of opportunity to build a sound regulatory framework for the ESG funds sector to address greenwashing risk.

The recent proposal of the European Commission for a regulation on ESG rating activities has the potential to improve the transparency and comparability of ESG ratings, thus contributing to financial stability.[157] The comparability of ESG ratings across a growing number of providers is currently limited. This is due to several factors, including methodological differences, amid a sizeable growing market for sustainable finance instruments. The proposed regulation seeks to achieve these objectives by introducing transparency requirements related to ESG ratings, and rules on the organisation and conduct of ESG rating providers[158]. From a macroprudential perspective, the current lack of transparency prevents comparability and is an impediment to the consistent use of ESG data among financial market participants. This in turn hampers the ability of ESG ratings to provide investors with effective signals for an efficient capital allocation, which is key in enabling the capital markets to support the funding of the green transition. In this context, strengthening the reliability and comparability of ESG ratings will be essential in facilitating efficient market pricing, thus supporting financial stability. It will also make us better able to monitor and address the impact of climate change on financial stability.

It is important to establish a sound and robust monitoring framework for greenwashing risks, as they are capable of affecting the entire system and their impact on financial stability is still fraught with uncertainty. Beyond the urgent need to: (i) converge towards robust standards, definitions and labels in the sustainable finance sphere; (ii) close climate data gaps; and (iii) enhance disclosure quality; competent authorities would do well to establish oversight mechanisms for monitoring compliance with greenwashing regulations, and also develop the

---

154 See ESMA (2023a).

155 Forthcoming ECB publication.

156 Strategies are assessed and provided by Morningstar.

157 **Proposal for a regulation on the transparency and integrity of Environmental, Social and Governance (ESG) rating activities**, European Commission, 13 June 2023.

158 According to the regulation, ESG rating providers must: (1) be authorised and supervised by ESMA to provide ESG ratings in the Union; (2) comply with organisational and governance requirements and processes set out in the proposed regulation; (3) comply with transparency requirements, including disclosure to the public of the methodologies, models and key rating assumptions used in ESG rating activities; and (4) comply with requirements regarding independence and conflicts of interest.

appropriate enforcement tools. Welcome steps are already being taken in this direction, including the agreement on an externally-verified European green bond standard[159], linked to the EU Taxonomy and with ESMA supervision of external reviewers, together with additional voluntary transparency rules for other sustainable bonds. A reliable, verifiable and transparent green bond standard will strengthen the credibility of this asset class, reduce reputational risks for issuers and investors, and mitigate greenwashing. This, in turn, will lead to improved pricing of green bonds, support the further growth of the segment, and strengthen the contribution made by green bonds to the EU's environmental objectives. To further mitigate greenwashing concerns, it is important that the Commission standard becomes the prime green bond standard. Close monitoring of its implementation will be needed, to assess its effectiveness in mitigating greenwashing and fostering market take-up of green bonds, including a commitment to consider options for making the standard mandatory. Possible further regulatory action might need to be considered to address greenwashing concerns and ensure minimum safeguards in ESG markets. Resources should also be provided to increase general public knowledge and empower consumers and investors to make informed decisions when it comes to the risks of greenwashing and the importance of critically assessing environmental claims.

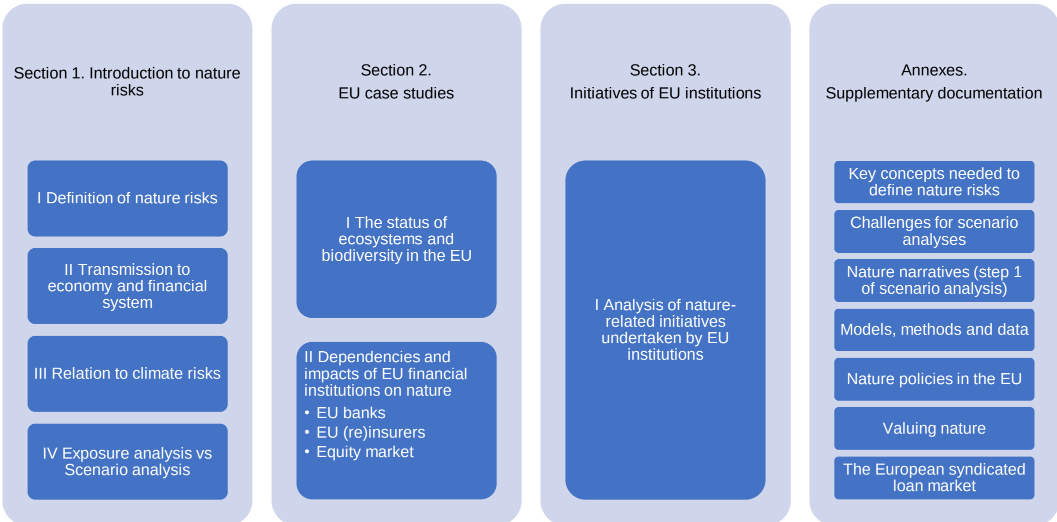
Further analysis is needed to estimate the impact of greenwashing on financial stability. Various reports released by the European supervisory authorities show that greenwashing can be a driver for the materialisation of several standard financial risks. Additional analysis is needed to assess the impact of greenwashing risks on financial stability so as to identify, measure, and manage the economic risks associated with emerging environmental investments. Detecting and preventing greenwashing is paramount to prevent long-term damage to the financial sector and to establish and implement effective regulations and policies to address greenwashing risks, thus cementing investor confidence in green products. This will be key to enabling the transition to a low-carbon economy and successful ESG investing.

[159] See press release titled *Sustainable finance: Provisional agreement reached on European green bonds*, available at https://www.consilium.europa.eu/en/press/press-releases/2023/02/28/sustainable-finance-provisional-agreement-reached-on-european-green-bonds/.

5 Nature-related risks

Even if often overlooked, nature plays a fundamental role in enabling economic activity, and so disruptions to the natural environment harbour the potential to significantly affect the economy and undermine financial stability. Our economies, and therefore also financial institutions as enablers of economic activity, are highly dependent on nature. According to preliminary estimates, 75% of corporate loans among euro area banks and 31% of investments in corporate bonds and equity among EEA insurers are in sectors that are highly reliant on at least one service that we get from nature, also referred to as ecosystem services. The largest dependencies of the euro area economy and its financial system are on services such as surface and ground water, mass stabilisation and erosion control, as well as flood and storm protection. These dependencies imply that the degradation of nature could have a profound impact on EU economies and financial systems.[160]

Figure 16
Chapter outline



Source: ECB/ESRB Project Team on Climate

While there is a growing body of research on the materiality of nature-related risks for the economy and the financial sector, further work is needed to identify, assess and mitigate these risks. This section is organised as follows (Figure 16 for a graphical representation): Section 5.1 builds on existing work to propose a Eurosystem definition of nature-related financial risks (NRFRs); Section 5.2 identifies and assesses these risks for the EU banking and insurance sector using an exposure methodology; and Section 5.3 outlines the initiatives currently being undertaken

[160] See NGFS (2022a).

by a number of EU institutions. The supplement to this report provides further information on, among others, the data and methodologies that can be used to further assess these risks.

5.1 Introduction to nature-related risks

5.1.1 Definition of nature-related financial risks

For the purposes of this report, nature is understood as the biotic (living) and abiotic (non-living) elements on our planet, including biodiversity as well as climate.[161] These elements combine to form ecosystems that yield a flow of benefits to people, otherwise known as ecosystem services. The ability of nature to provide these ecosystem services depends in particular on its biodiversity, defined as the variability among living organisms. While the terms biodiversity, ecosystems, and ecosystem services are sometimes used in this report to reflect the specificities of the datasets and methodologies used, we consider these to fall under the umbrella of the term "nature" and therefore feed into the definition of nature-related financial risks. Please refer to Annex 4.1 for more detailed definitions.

As with climate-related financial risks, nature-related financial risks can be categorised into physical and transition risks. The NGFS defines NRFRs as the risks of negative effects on economies, individual financial institutions and financial systems that result from:

i. the degradation of nature, including its biodiversity, and the loss of ecosystem services that flow from it (i.e. physical risks); or

ii. the misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature (i.e. transition risks).[162] Litigation risks are considered a subset of physical and transition risks, since they can arise from the materialisation of both these risk types.

Physical risks can be chronic, acute, or both. Chronic physical risks accumulate and materialise gradually over time, as in the case of land degradation rendering it unsuitable for crop cultivation. Acute physical risks are abrupt and could also involve passing a tipping point. In the EU, a decrease in the availability of freshwater could be a significant source of physical risk. Water-dependent sectors in the EU – such as manufacturing and agriculture but also power and transportation – generated 26% of the EU's annual gross value added in 2015 and some sectors are highly dependent on the availability of freshwater .[163]

Transition risks could result from unanticipated changes in policies, technologies and consumer and investor preferences. In the context of freshwater availability, current production and consumption levels greatly affect this ecosystem service, which could in the future become subject to more stringent regulation or changes in consumption habits. Such constraints might not

---

161 This is the definition used in the NGFS Conceptual Framework on Nature-related Financial Risks (**https://www.ngfs.net/sites/default/files/medias/documents/ngfs_conceptual-framework-on-nature-related-risks.pdf).**

162 See **ngfs_conceptual-framework-on-nature-related-risks.pdf.**

163 See Ecorys (2018), "The Economic Value of Water – Water as a Key Resource for Economic Growth in the EU".

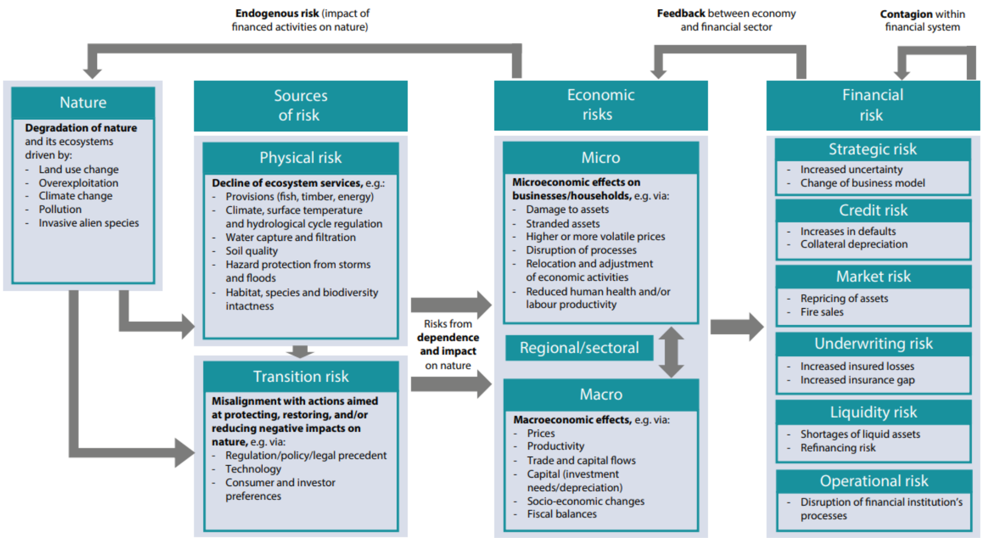
be appropriately factored in current plans of multiple sectors relying directly or indirectly on this resource.

Nature-related financial risks are partly endogenous, meaning that economic and financial actors can affect their magnitude. Through their impact on nature, economic and financial actors affect the extent of the nature-related financial risks they would have to manage. While these actors could contribute to nature degradation and therefore potentially increase their nature-related physical and/or transition risks, they could also generate positive impacts on nature and potentially reduce these risks.

5.1.2 Transmission of nature-related risks to the economy and the financial system

Figure 17

Transmission channels of nature-related risks



Source: NGFS Conceptual Framework on Nature-related Financial Risks (2023).

Physical and transition nature-related risks affect the economy through direct and indirect transmission channels. Direct or first-order effects result from the direct dependence or impact of primary producers and consumers on nature. Agriculture, mining and infrastructure are among the sectors most exposed to such effects. Meanwhile, indirect or second-order effects transmit direct effects through value chains and can therefore lead to an amplification of direct effects. Retail and services are examples of sectors that can be affected indirectly.[164] When assessing the potential magnitude of direct and indirect effects, a determining factor is the ability of the affected businesses

[164] Further details and examples of affected sectors can be found in *Sector guidance* (Version 1.0), TNFD, September 2023; *A Biodiversity Guide for Business*, WWF, May 2022; *The Biodiversity Crisis Is a Business Crisis*, Boston Consulting Group, 2021; *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy*, World Economic Forum, 2020.

to find substitutes to the input factors nature is providing. Global nature degradation makes geographical substitution increasingly difficult. Technological substitution raises the important question of how substitutable nature is by non-natural (i.e. manufactured) capital.

Physical and transition risks transmitted via direct and indirect channels can lead to impacts on micro and sectoral/regional levels. From a microeconomic perspective, these risks can affect households and businesses that are directly or indirectly reliant on nature, or that affect nature. As an example, the materialisation of physical risks such as the deterioration of ecosystems could lead to an increase in the cost of production inputs for individual firms. Tighter regulation on the import of commodities due to the EU Biodiversity Strategy is an example of materialising transition risk that could reduce the availability of exploitable resources.

Direct and indirect impacts could affect entire supply chains and have macroeconomic effects (Power, Dunz and Gavryliuk, 2022). The loss or degradation of ecosystem services could create inflationary pressures due to commodity price hikes. It could also negatively affect productivity. For instance, air pollution could have a negative impact on human health and cognitive performance, reducing labour productivity (Chang et al., 2019). Additionally, deforestation and species loss make pandemics more likely (Tollefson, 2020). Johnson et al. (2021) made a first attempt to quantify the macroeconomic consequences of nature loss, finding that the resulting loss of ecosystem services caused an annual decline of up to 2.3% in global GDP through to 2030.

The economic effects of nature-related physical and transition risks can have an impact on individual financial institutions and the entire financial system (Table 6). Financial intermediaries are exposed to affected households, businesses and governments through their loans, debt and equity holdings. Nature-related financial risks, similarly to climate-related financial risks, materialise in existing risk categories, such as credit, market and operational risk. These risks can affect individual financial institutions or, via contagion, spread to other financial institutions and potentially pose a threat to financial stability.

Table 6
Examples of nature-related shocks affecting prudential risks

Prudential risk category	Examples of the impact of nature-related shocks
Credit risk	Increased production costs and supply chain disruptions diminish the profitability of businesses, affecting their repayment capacity and therefore their probability of default.
Market risk	The EU's proposal to achieve a minimum 20% reduction in fertiliser use by 2030 could threaten the profitability of chemical companies, resulting in repricing of their shares.
Operational risk	Financing controversial practices such as deforestation or a lack of sufficient ESG policies could elicit a negative response from investors and carry reputational or even legal risks for financial institutions.

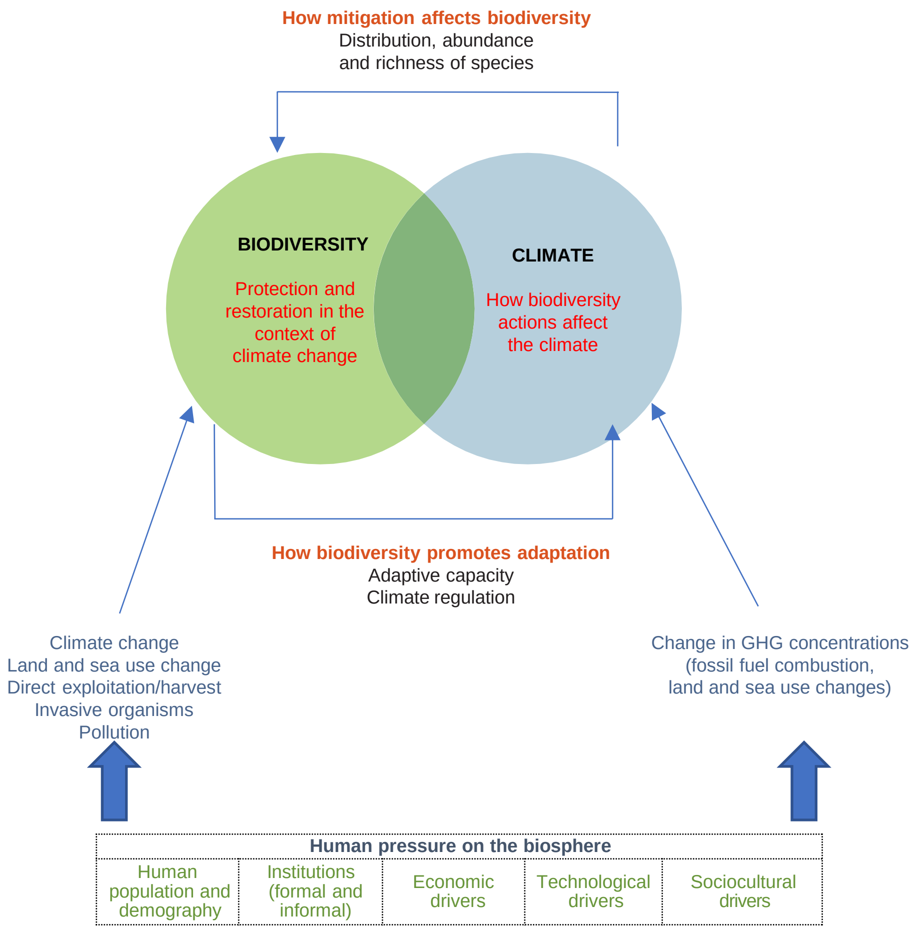
Source: ECB/ESRB Project Team on Climate

5.1.3 The interaction of climate risks with broader dimensions of nature

Climate change, biodiversity loss and ecosystem degradation – all of which fall under the umbrella of nature as defined in Section 5.1.1 – are pressing issues. There are four potential links between climate and other nature dimensions that are relevant when it comes to assessing the full economic and financial stability impact of nature-related risks.[165] These are: 1) climate change as a driver of nature degradation; 2) climate mitigation policies as a potential driver of nature degradation; 3) nature degradation as a driver of climate change; and 4) nature restoration as a tool for mitigation and adaptation. Below we further explore why it is important to consider risks stemming from climate and the other dimensions of nature in an integrated manner (Figure 18).

Figure 18

Interconnections between biodiversity and climate



Source: ECB/ESRB, adapted from Pörtner et al. (2021).

[165] NGFS Conceptual Framework on Nature-related Financial Risks.

Climate change is one of the most prevalent threats to ecosystems, individual species and the interactions between them (IPBES, 2019[166]). According to the contribution of the second working group of the IPCC to the sixth assessment report titled "Climate Change 2022: Impacts, Adaptation and Vulnerability" (IPCC, 2023[167]), progressive warming in Europe has led to a reduction in suitable habitat space for current terrestrial and marine ecosystems and this problem will only worsen if we will pass the 2 °C threshold. Moreover, fire-prone areas will expand across the continent, threatening biodiversity and carbon sinks. In southern Europe, more than a third of the population will be exposed to water scarcity, the risk of which will become high with a 1.5 °C temperature increase and very high with a 3 °C increase. By ignoring the impact of climate change on nature loss, we run the risk of underestimating its economic and financial impact.

Preservation and restoration of nature typically helps to mitigate climate change, with the resulting positive impact on nature; well-managed ecosystems could provide effective and feasible contributions, known as Nature-based Solutions (NBSs), to climate change mitigation and adaptation. More precisely, NBSs have been proposed to increase carbon storage, or to avoid further greenhouse gas loss from soil, forests and oceans (Nature, 2022[168]). For example, Bertram et al. (2021)[169] find that carbon sequestration and storage in mangroves, salt marshes and seagrass meadows is an essential coastal "blue carbon" ecosystem service for climate change mitigation.

Combating climate change is not always positive for nature. For example, afforestation focuses on rapid tree growth rather than on native habitat recovery, with some programmes relying on monoculture plantations made up of a fast-growing tree species that could harm biodiversity. Beyond afforestation, bioenergy with carbon capture and storage (BECCS) is another land-based climate mitigation technique that could pose risks to biodiversity (Heck et al., 2018[170]).[171] Additionally, the harnessing of critical materials and elements that are crucial for the clean energy transition, such as rare-earth metals, is very likely to have a negative impact on the environment (International Energy Agency, 2022[172]). Overall, solutions developed to address climate change have a broader impact on nature, and these should be factored in the assessment of these solutions and the design of a mitigation strategy.

5.1.4 Exposure analysis vs Scenario analysis

Various financial and environmental studies contend that three components are needed to conduct a forward-looking assessment of nature-related financial risks, otherwise known as

---

166 See **https://www.ipbes.net/global-assessment.**

167 See **https://www.ipcc.ch/report/ar6/wg2/.**

168 "The eco–climate nexus", *Nature Climate Change* 12, 595 (2022): **https://doi.org/10.1038/s41558-022-01418-1**).

169 Bertram, C., Quaas, M., Reusch, T.B.H. et al., "The blue carbon wealth of nations", *Nature Climate Change* 11, 704–709 (2021): **https://doi.org/10.1038/s41558-021-01089-4**).

170 Heck, V., Gerten, D., Lucht, W. et al., "**Biomass-based negative emissions difficult to reconcile with planetary boundaries**", Nature Climate Change 8, 151–155 (2018).

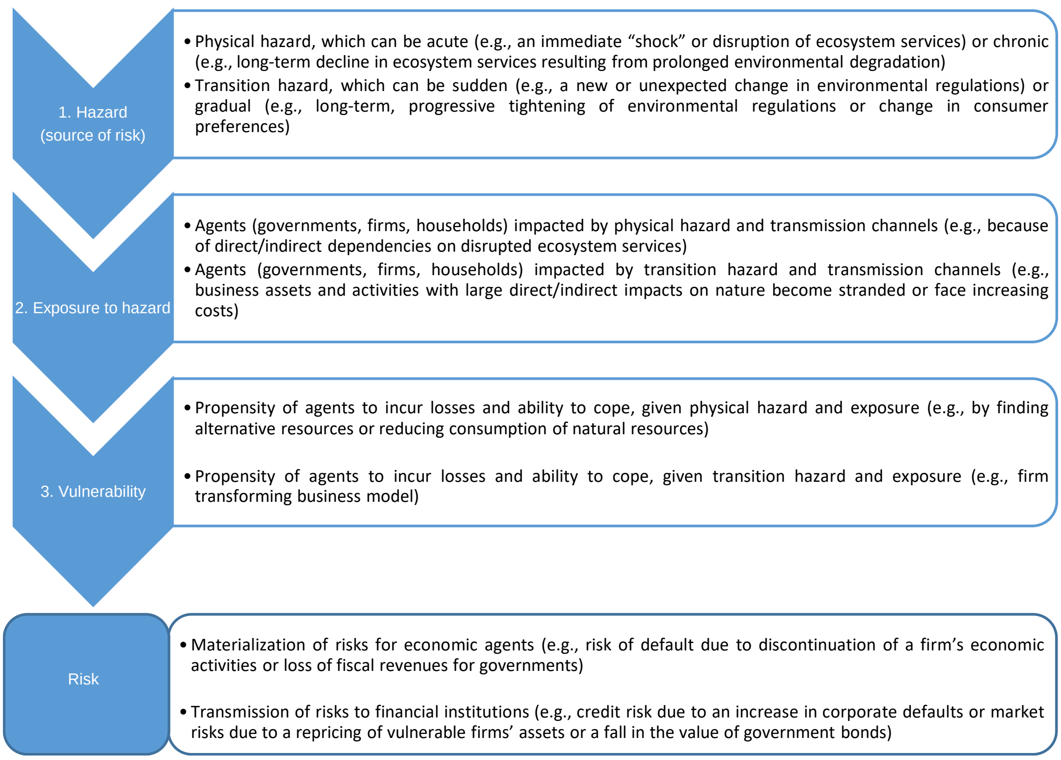
171 BECCS is a still-emerging technique in which crops (biomass) are grown and then burned in a power plant to generate energy, while the resulting CO2 is captured before it can be released into the air. All scenarios for how the world can succeed in limiting global temperature rise to 1.5 ºC above pre-industrial levels rely to some degree on afforestation and/or BECCS.

172 International Energy Agency, The Role of Critical Minerals in Clean Energy. World Energy Outlook Special Report (2022).

a scenario analysis (Figure 19): (i) a scenario of the hazards or shocks that could translate into financial risks; (ii) metrics showing the exposure of financial institutions (or the firms in their portfolios) to these hazards/shocks, including their transmission channels; and (iii) an assessment of the vulnerability of financial institutions, i.e. their sensitivity and adaptive capacity (or that of the firms in their portfolios).

Figure 19

The three steps needed to conduct a nature-related financial risk assessment



Source: NGFS Technical document on nature-related scenarios (2023).

At the current juncture, there are three main challenges when it comes to conducting such an analysis. First, we need to a have clear idea of the type of hazards or shocks that could occur. However, these remain uncertain, and no scenarios have yet been designed for central banks and financial supervisors to assess those risks, unlike for CRFRs[173]. Second, once the hazard or shock scenario has been defined, we need to assess the exposure of agents (whether individuals, businesses, financial institutions or sovereigns) to this shock. Exposure can be defined as being in places and settings that could be adversely affected by the hazard. Estimating this exposure is difficult without a clear idea of what the hazard is and very granular data. Third, we need to understand the risk (sensitivity) associated with a given hazard and exposure, as exposure does not automatically translate into loss. Please refer to Annex 4.2 for more information on the challenges in how to conduct a nature scenario analysis, including the proposed approach of the NGFS to tackle the creation of nature narratives (step 1 of Figure 19), and Annex 4.3.3 for the

[173] NGFS, 2020a.

recommendations of the NGFS when it comes to modelling the interactions between nature (degradation) and the economy (also Step 1).

Given the lack of commonly available nature-related scenarios and methodologies to measure the vulnerability of individual agents, a large part of the incipient literature has focused on an exposure approach. This approach consists in identifying the dependencies and impacts that the exposures of financial institutions have on nature, and using them as a proxy for physical and transition risk respectively. This is also the approach largely used in Section 5.2 for the quantitative case studies. Part of the reason for the proliferation of this exposure approach is the existence of a variety of datasets that facilitate this type of analysis. Please refer to Annexes 4.3.1 and 4.3.2 on current datasets used for exposure approaches, and on future data needs to further develop such assessments.

5.2 EU case studies

As the degradation of nature and its ecosystems is a source of physical risk, understanding the state of nature in the EU – as also expressed by the health of ecosystems and degree of biodiversity – is key to identifying relevant sources of physical or transition risk. The state of nature can be determined in various ways, including monetary and non-monetary approaches (Annex 4.4.1). In particular, the assessments of the extent to which different aspects of our natural environment are “healthy” or “degraded” and change over time (Box 5) provide a starting point for thinking about potential sources of physical risk and the likelihood of them materialising, especially in sectors that are the basis of our food systems (Box 6) (see also Section 5.2.1). Furthermore, the policies now being undertaken in response to nature degradation in the EU are a useful platform for exploring potential sources of transition risk (Annex 4.4) Identifying these sources of physical and/or transition risk is part of the first step of conducting a scenario analysis, i.e. a forward-looking risk assessment, as outlined in Section 5.1.4.

Knowing the extent to which the EU financial system is exposed to nature (degradation) is also crucial if we are to grasp the potential financial stability repercussions of nature degradation. Given the challenges in conducting a forward-looking assessment of nature-related risks, we use an exposure methodology to identify the dependencies and impacts of European financial institutions on nature. These dependencies and impacts can be thought of as proxies for physical and transition risk (Sections 5.2.2 and 5.2.3, and Boxes 7 and 8).

5.2.1 The status of ecosystems and biodiversity in the EU

Europe is home to a wealth of habitats and species — both land-based and marine.[174] **However, centuries of human activity has taken a toll on Europe’s natural capital.** Our natural capital has been transformed and heavily impacted over the years, with a notable acceleration over the past fifty years. Most of Europe’s terrestrial and aquatic species and habitats are now facing an uncertain future unless urgent and more ambitious action is taken to decisively reverse current

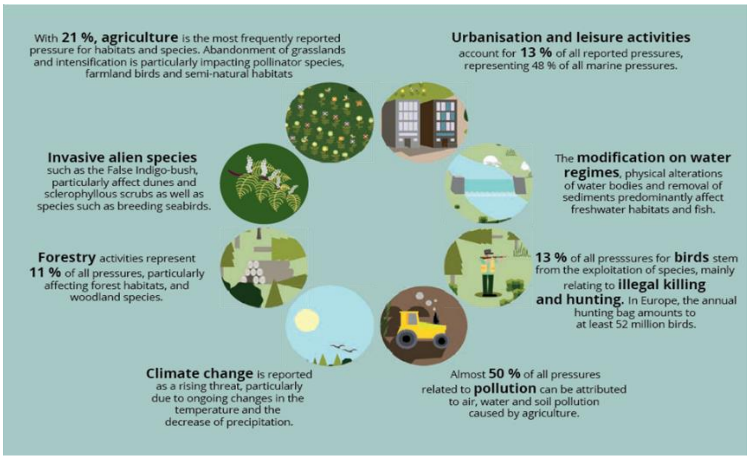
174 See ***Seas and coasts***, European Environment Agency.

trends. Despite some progress, most protected habitats and species have either poor or bad conservation status. Destruction or overexploitation of ecosystems, pollution, climate change, the introduction of invasive species, urban sprawl and landscape fragmentation are the main reasons behind this decline (Figure 20).

Degradation affecting species and their habitats is a symptom of the (qualitative and quantitative) erosion and (eventually loss) of ecosystem services. As industry and companies rely on ecosystem services, the degradation of habitats and species suggests direct risks for various sectors of the economy. Construction, agriculture, and processed food and drinks are just some of the key sectors affected. To give an example, the decline of marine fish stocks has a negative impact on the fisheries sector, while the decline in pollinators affects agriculture. Overall, 81% of habitats at the EU level are in poor condition, with peatlands, grasslands and dune habitats in the worst shape despite the critical role of these habitats (peatlands are key in climate change mitigation, grasslands are important habitats for pollinators, while dunes contribute to flood control, thus reducing flood damage and protecting coastal areas).

Figure 20

Drivers of biodiversity loss



Source: EEA (2020).

To limit both physical risks and transition risks stemming from a disorderly implementation of its response to the degradation of nature, the EU needs to deliver in a timely manner on the commitments of its Biodiversity Strategy for 2030. To succeed, it must look to implement new measures or scale up and monitor those currently being implemented. At the same time, nature protection needs to be complemented by nature restoration, through actions such as removing barriers along rivers or restoring degraded habitats. At least 226,000 square kilometres of protected habitat needs to be restored to ensure its long-term viability.[175]

175 See Annex I of the **Habitats Directive**

Box 5

Ecosystem accounting – The state of ecosystems in Europe

Ecosystems play a critical role in our economy, as they provide a range of essential ecosystem services (Vysna et al., 2021; La Notte et al., 2021). Hence, it is of vital importance that they remain in good condition.[176] The Ecosystem Accounting framework is used to monitor the state of ecosystems and keep track of both the stock of ecosystem assets and the flow of ecosystem services.[177] The three fundamental modules of ecosystem accounting are ecosystem extent, ecosystem condition, and ecosystem services accounts. Ecosystem extent accounts provide information about the extent or size of different ecosystems and how they change over time. Ecosystem condition accounts reveal an ecosystem's overall health and its ability to supply ecosystem services. Ecosystem services accounts offer a more comprehensive view of an ecosystem's state by considering both the extent and condition of the ecosystems that are already reflected in the flow of services.

The Integrated Natural Capital Accounting (INCA) project initiated production of ecosystem accounts for the EU-27. Results from the INCA project suggest that the flow of nine ecosystem services had a value of €187 billion in the accounting year 2018 (in 2012 prices), with woodland and forest playing the biggest role (Figure A). More accurately, forest and woodland provides just over half of the total value, while cropland contributes 30% and urban ecosystems less than 1%. On the services side, water purification and nature-based recreation hold the highest value, each representing roughly 27% of the total value, while habitat and species maintenance accounts for 17% of the aggregated value of all ecosystem services. In terms of use by sectors, almost 37% of the value of flow is used by the primary sector, which includes agriculture and forestry. The secondary sector and the tertiary sector combined use about 10% of the value of services, while a further 31% is used by households and the remaining 21% by the global society (Vysna et al., 2021; La Notte et al., 2021).

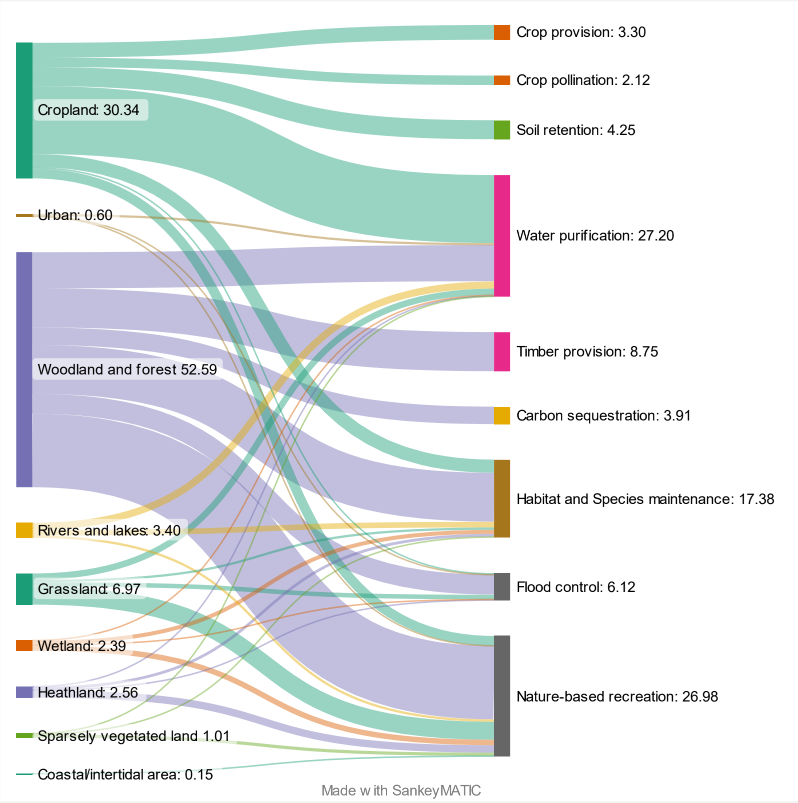
[176] See Vysna et al. (2021) and La Notte et al. (2021).

[177] This innovative framework is based on the globally recognised standard of the System of Environmental-Economic Accounting—Ecosystem Accounting; see UN et al. (2021).

Figure A

Supply of ecosystem services

(% of total monetary value of the supply of ecosystem services by ecosystem units)



Sources***: https://ecosystem-accounts.jrc.ec.europa.eu/; https://data.jrc.ec.europa.eu/collection/maes.***
Note: The Common International Classification of Ecosystem Services (CICES) classifies over the 55 biotic services.

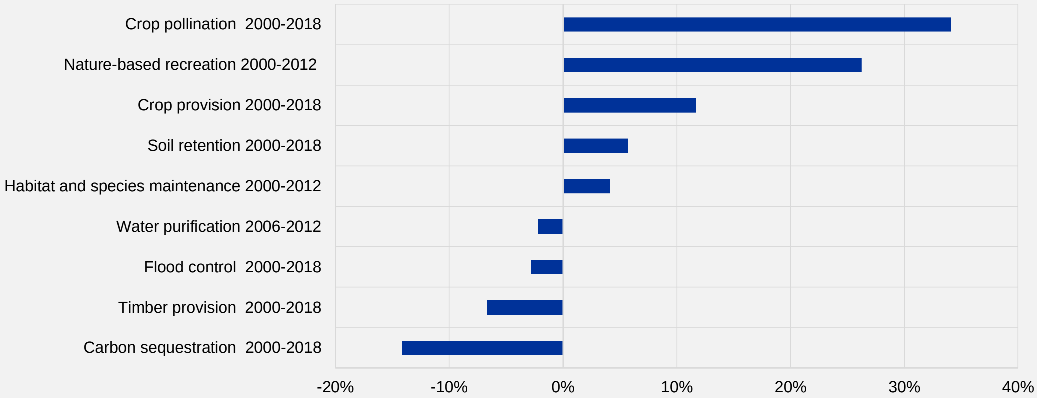
When looking at historical progress, the results show that nature-based recreation, crop pollination and crop provision have undergone a substantial positive change (>20%, >30%, and >10%, respectively), while water purification, flood control, timber provision and carbon sequestration services have decreased (Chart A). By tracking the changes in the value of the flow of ecosystem services across accounting periods, it is possible to identify alterations in the current state of ecosystems and gain insights into their future state. The value of flow is measured in physical terms. Carbon sequestration has experienced the highest negative change, largely due to alterations in the extent of ecosystems, such as grasslands, that contribute to carbon removal. From the use perspective, the agricultural sector has seen lower use of ecosystem services due to a reduction in flood control and water purification services. The secondary and tertiary sectors have also seen lower use, primarily due to a reduction in the flow of water purification services. The forestry sector has been significantly affected by the reduction in the flow of timber supply.

The increase in crop provision, pollination, and recreation services is primarily driven by demand, and therefore, an increase in use does not necessarily indicate an increase in potential supply. Furthermore, the interpretation of changes in service flow depends on the definition of the service (La Notte et al., 2021). For example, a decrease in water purification use suggests reduced pollution from nitrogen inputs and a lower need for removal, as water purification acts as a sink service that removes pollutants.

Chart A

Change of ecosystem services flow

(% change of the estimate of the service in physical terms between accounting periods)



Source: ***https://ecosystem-accounts.jrc.ec.europa.eu/*** *and* ***https://data.jrc.ec.europa.eu/collection/maes***
Notes: There are over the 55 biotic services classified by CICES. For each service the units of estimation are different (e.g. crop provision is measured in tons, while wood provision is measured in m3). A negative change means a decrease in the flow of ecosystem services between the accounting periods, i.e. from 2000 to 2018.

Box 6

Using ecosystem accounting data to derive ecosystem dependencies of the agricultural sector

Ecosystem services can be defined as the contribution of ecosystems to economy and society. Such contribution can be exerted in two ways. First, it can take place directly in the form of ecological inputs to production processes (growth of food and non-food crops, wild pollinators, etc.), or it could act by removing negative externalities from production (e.g. air filtration, water purification), or protecting activities from physical and biological hazards (e.g. flood control, pest regulation). Second, when there are overarching environmental goals acknowledged at international level (such as mitigating climate change and halting biodiversity loss), sound ecosystem management can help us pursue and achieve targets (e.g. carbon sequestration and species maintenance).

According to INCA[178], a flow of ecosystem services is registered when socio-economic demand can be matched with and met by ecological supply from ecosystems. The actual flow of ecosystem services provided is registered as a transaction originating from ecosystem types directed to

[178] INCA is the EU framework for generating ecosystem services accounts based on System of Environmental-Economic Accounting (SEEA) Ecosystem Accounting (EA) standards. See Section 4.2.1; La Notte et al. (2022b); and Edens et al. (2021).

economic sectors (primary, secondary, tertiary sectors, households, etc.) in the form of a supply and use table.

Socio-economic demand can exceed ecological supply, thus resulting in a mismatch. This can occur (i) if an ecosystem service is used beyond its sustainability thresholds (e.g. where natural resources are extracted beyond their regeneration rates, or where pollutants are emitted beyond an ecosystem's capacity to absorb them); or (ii) due to an absence of ecosystems able to provide the services needed (e.g. lack of vegetated land to control the risk of erosion, or lack of habitats suitable to host wild pollinators). Average mismatch values can be calculated for the main groups of ecosystem services accounted in INCA, focusing on the agricultural sector as an initial application,[179] although this approach can be replicated for other sectors as well. Specifically, (i) the group "ecological inputs" includes pollination and soil retention, (ii) the group "pollution removal" includes water purification, and (iii) the group "protection" includes flood control.

Table A shows the outcomes of ecosystem service mismatch accounts expressed through a (dimensionless) ES vulnerability indicator. The agricultural sector depends on these services and the respective mismatch highlights where a lack of ecosystem service provisioning exists and, therefore, where the functioning of the agricultural sector is impaired. More precisely, negative sign indicators confirm the existence of mismatches, which in this application are explained as follows: in countries with negative ecological inputs, wild pollinators and fertile soil may be an issue for crop production; in countries with negative pollution removal, there is an excessive use of mineral fertilisers that will eventually degrade all inland watercourses, with the ensuing health and legal consequences; and in countries with negative protection, agricultural fields receive no ecosystem protection from the risk of flooding.

When focusing on the countries with the most developed agricultural sector, Italy, Spain and the Netherlands suffer from ecosystem criticalities, although for different reasons. Chart A reports ecosystem service mismatches in the countries where the agricultural sector is a leading economic activity. It considers two indicators: Gross Value Added, which ranks France, Germany, Italy and Spain as the main producer countries; and exports of agricultural products, which ranks Germany, France, the Netherlands, Spain and Italy as the main exporting countries. As can be seen, the agricultural sector in Italy, Spain and the Netherlands shows ecosystem criticalities. In the case of Italy and Spain, the protection role of ecosystems would need to be safeguarded as agricultural fields in many areas of these countries are exposed to the avoidable risk of flooding. In the case of the Netherlands, nitrogen inputs in agriculture still generate a level of pollution that the environment is unable to absorb. Pollution removal is, however, critical for all the selected countries.

179 See La Notte et al. (2022a).

Table A

Mismatch indicators for the three groups of ecosystem services in the EU-27

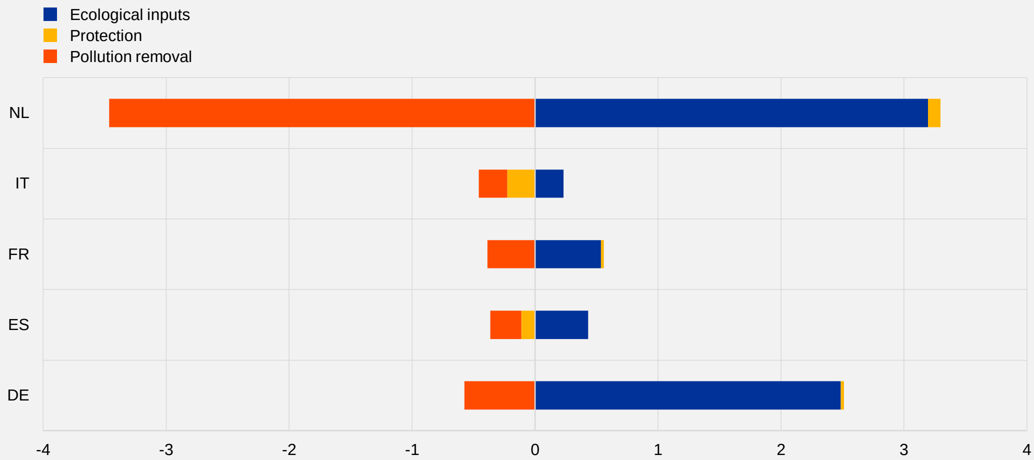
Countries	Ecosystem Service vulnerability components		
	Ecological inputs	Pollution removal	Protection
AT-Austria	1,536	-0,255	0,034
BE-Belgium	1,631	-0,578	0,170
BG-Bulgaria	-0,929	-0,229	-0,056
CZ-Czech Republic	2,830	-0,459	-0,036
DE-Germany	2,486	-0,576	0,025
DK-Denmark	2,137	-0,459	-0,030
EE-Estonia	2,928	0,523	0,277
EL-Greece	-0,522	-0,208	-0,167
ES-Spain	0,432	-0,250	-0,113
FI-Finland	2,894	2,363	0,148
FR-France	0,537	-0,388	0,022
HR-Croatia	2,320	-0,189	0,118
HU-Hungary	1,062	-0,446	-0,214
IE-Ireland	3,101	-0,274	0,342
IT-Italy	0,230	-0,232	-0,225
LT-Lithuania	3,211	-0,525	0,228
LU-Luxembourg	2,468	-0,397	0,179
LV-Latvia	3,306	0,096	0,280
NL-Netherlands	3,197	-3,464	0,100
PL-Poland	2,772	-0,653	0,128
PT-Portugal	1,194	-0,241	0,123
RO-Romania	-0,502	-0,379	-0,197
SE-Sweden	3,000	2,809	0,013
SI-Slovenia	2,539	-0,195	0,130
SK-Slovakia	1,434	-0,212	-0,217

Source: Adapted from La Notte et al. (2022a)
Note: The ecosystem services vulnerability indicator (used to report mismatches) displays the average difference per country between each pixel value (100 m x 100 m) and the mean for the pilot year 2012.

While the analysis of direct contributions from ecosystem services to the EU economy does not point to warning-level criticalities, the inclusion of indirect contributions reveals significant mismatches between supply and demand. As shown in Chart A, the countries leading the EU agricultural sector do not appear to suffer any huge criticality as a result of direct ecological inputs. In other words, if this were the only kind of contribution accounted for from ecosystems, then no major issue would be detected. However, the analysis including indirect contributions demonstrates how important it is to identify and assess ecosystem services with protection and pollution removal roles. More broadly, since the dependency on nature is multifaceted, the design and planning of appropriate policy options should take into account how ecosystem services interact with production processes and human activities and identify each individual flow of services and the role it plays.

Chart A
Mismatch indicators for the three groups of ecosystem services in the most affected EU countries

(index)



Source: Adapted from La Notte et al. (2022a).
Note: The ecosystem services vulnerability indicator (used to report mismatches) displays the average difference per country between each pixel value (100 m x 100 m) and the mean for the pilot year 2012.

5.2.2 Dependencies and impacts of EU banks on ecosystem services

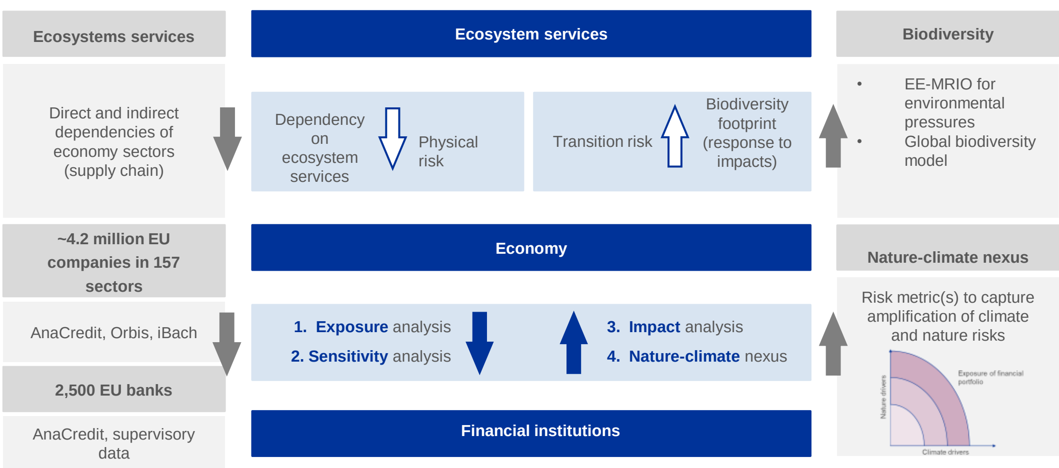
An analysis of the dependency and impact of financial institutions on ecosystem services – the so-called exposure analysis discussed in Section 5.1.4 – has increasingly become the go-to approach for estimating nature-related financial risks in the central banking and supervisory community. Van Toor et al. (2020) were the first to conduct such a dependency and impact analysis. They found that 36% of the portfolios of Dutch financial institutions that they examined was either highly, or very highly, dependent on one or more ecosystem services. Svartzman et al. (2021) conducted a similar analysis and found that 42% of the value of securities held by French financial institutions came from issuers that were either highly, or very highly, dependent on one or more ecosystem services. Comparable analyses were conducted by Calice et al. (2021) for Brazil and by World Bank and Bank Negara Malaysia (2022) for Malaysia, which found even larger dependencies.

The quantitative assessments to have been carried out so far have tended to focus on the exposures of financial institutions to the provision of ecosystem services via (part of) their portfolios and how they contribute to biodiversity loss. Most of these studies rely on external data providers and should be considered preliminary. ENCORE is the main dataset used to map the dependency of economic activities on ecosystem services and measures how each economic sector depends on a given ecosystem service. Since each economic sector depends on a multitude of ecosystem services, ENCORE provides a set of materiality scores per sector, which range from no dependency to very high dependency. This enables us to quantify the dependency of an institution's portfolio on a set of ecosystem services, as a proxy for its vulnerability to changes in the provision of these services.

Building on previous studies, the ECB (Ceglar et al. 2023a and Ceglar et al. 2023b) developed a quantitative assessment of the dependencies and impact of EU banks on ecosystem services, measuring also the sensitivity of potential losses among banks to future biodiversity scenarios. The assessment involves: (1) an assessment of dependencies among companies and banks to ecosystem services in the EU; (2) an assessment of bank portfolio sensitivity to ecosystem service disruptions; (3) an initial assessment of the climate-nature nexus, to identify areas particularly vulnerable to amplification mechanisms; and (4) an assessment of the impact of companies and banks on biodiversity losses (Figure 21). Importantly, this dependency and impact analysis substantially enlarges the samples covered in previous studies and includes almost all European bank loans to non-financial corporates.

Figure 21

Assessment of EU banks' dependencies and impacts on ecosystem services: project overview



Sources: Ceglar et al. (2023a) and Ceglar et al. (2023b).
Note: EE-MRIO means environmentally extended multi-regional input-output.

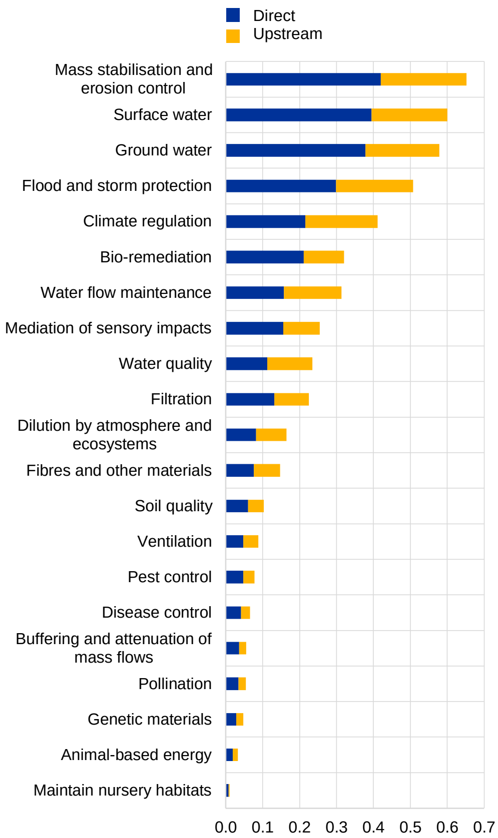
The exercise also proposes a new measure to combine the direct and indirect dependency of economic activities to ecosystem services, so as to also account for the supply chain of a given sector. Chart 31 shows the dependency of European companies (left) and consolidated banking groups headquartered in the euro area (right) to ecosystem services, distinguishing also between direct (Scope 1) and indirect (upstream) dependency, with the latter capturing the supply chain effects. The results indicate that companies and banks alike have a significant dependency on several ecosystem services through the economic sectors that they finance, with mass stabilisation and erosion control, surface water, and ground water representing the largest vulnerabilities. The charts also highlight the importance of including indirect dependencies via the supply chain, without which the final figures would substantially underestimate vulnerable exposures.

Chart 31

Dependency of euro area companies and banks to ecosystem services

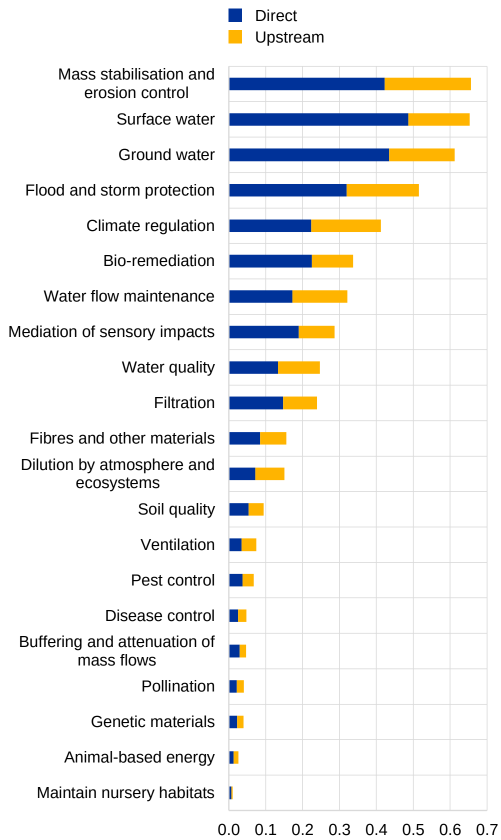
a) Direct and indirect dependency of euro area corporates on ecosystem services

(total dependency score, December 2021)



b) Direct and indirect dependency of euro area banks on ecosystem services

(total dependency score, December 2021)



Source: Ceglar et al. (2023a).
Notes: Panel a) shows the average dependency score among euro area NFCs. Panel b) shows the average euro area dependency score among banks weighted by the relative sizes of their loan portfolios. In turn, lender-level dependency scores are computed as weighted averages of borrower dependency scores, weighted by the relative importance of the borrower in the

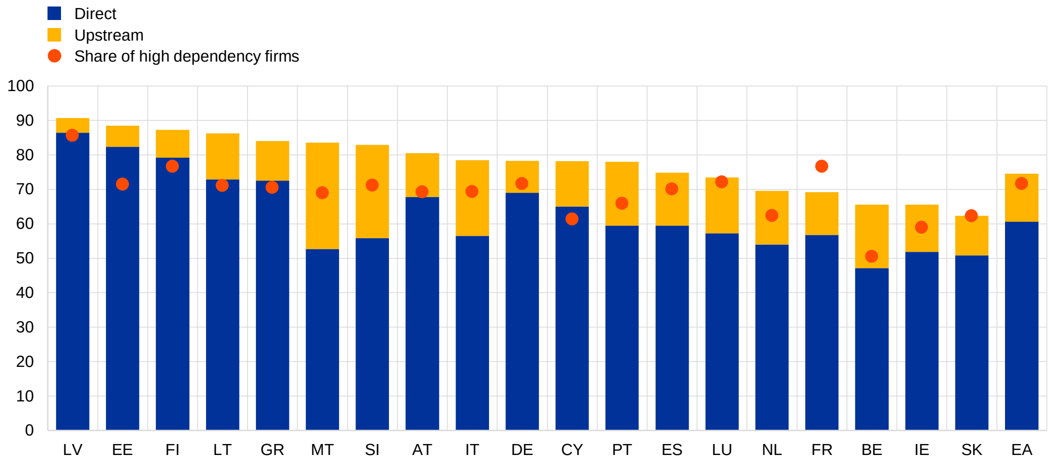
bank's overall corporate loan portfolio. Both panels distinguish between direct dependency and indirect dependency (upstream) through the supply chain.

Overall, approximately 72% of NFCs and 75% of all corporate loan exposures in the euro area have a high dependency on at least one ecosystem service. Chart 32 shows the total dependency (Scope 1 + upstream) of companies and corporate loans from banks, showing also differences across countries. When looking at the share of NFCs with at least one high dependency, the results do not indicate strong geographical heterogeneity, with all values being above 60% (except for Belgium). However, differences in the share of the upstream dependency component signal different levels of reliance on the supply chain, causing a particularly significant increase in the total dependency score in small open economies. Slightly more heterogeneous results can be observed when looking at banks' corporate credit portfolio exposures, which range from 60% to 90%. However, they are broadly consistent with the findings for NFCs.

Chart 32

Share of euro area firms and corporate loans highly dependent on nature

(Dec. 2021, share of loans (bars) and of NFCs (line) with a high dependency score on at least one ecosystem service)



Source: Ceglar et al. (2023a), based on AnaCredit and ENCORE.
Notes: Share of corporate loans and non-financial corporations with a high dependency score (greater than 0.7) for at least one ecosystem service. The share of firms in each country (dots) represents the overall proportion of NFC with high dependency on at least one ecosystem service in the sample. On the other hand, a loan is labelled as highly dependent when the borrowing NFC has a sufficiently high direct dependency score (blue bar) or sufficiently high dependency when also considering possible supply chain linkages (yellow bar) for at least one ecosystem service. Loans are grouped by lender's headquarter country.

The ECB study also provides insights into the sensitivity of credit portfolios among euro area banks to possible changes in a given ecosystem service and/or natural asset. This represents an important step forward in understanding the implications of nature degradation on financial stability, as it allows us to explore the extent to which different economic sectors – and thus banks' exposures to them – would sustain losses due to possible future trends in the provision of ecosystem services. Answering this question poses several challenges (Section 5.1.4), the main one being the lack of nature-related scenarios needed to shed light on what our economies might look like over the coming decades as a consequence of nature degradation and human action. For this reason, the methodology proposed in Ceglar et al. (2023a) is not intended as a scenario analysis, but as a sensitivity analysis to understand how expected losses on banks' credit portfolios may change over time if one natural asset becomes degraded.

The shock is applied to species abundance, which is used as a proxy for biodiversity intactness, and is calibrated following three different futures in terms of human pressure on the environment and climate change levels in 2050 (Schipper et al., 2020). The first scenario is a sustainability scenario combined with low levels of climate change (SSP1 x RCP2.6): it is characterised by relatively low population and consumption growth due to less resource-intensive lifestyles, more resource-efficient technologies, and increased regulation, among other factors. The second scenario combines a regional rivalry scenario with moderate levels of climate change (SSP3 x RCP6.0): it is characterised by high population growth, resource-intensive consumption, low agricultural productivity, and limited regulation of land use change, leading to continued deforestation. The third scenario integrates a fossil-fuelled development scenario with high levels of climate change (SSP5 x RCP8.5), and is characterised by low population growth, strong economic growth, a consumption-oriented and energy-intensive society, and highly intensive agricultural practices. The first scenario represents the best possible outcome and is used in the study as a baseline, while the second and third scenarios include only modest or no climate change mitigation policy and are considered adverse scenarios.

The expected losses are computed using both loan-specific features and nature-specific coefficients. Specifically, we use supervisory financial data to compute the exposure at default (EAD) and the LGD of any given loan. Meanwhile, we use the dependency of the bank counterpart on nature and the speed of degradation of biodiversity as our proxy for the changes in probabilities of default (PD) of NFCs. To capture the fact that different economic activities rely on biodiversity in different ways, the shock is computed both at a country level and at a watershed level. Watershed levels are used here to divide the landscape by focusing on water flows where biodiversity and ecosystems tend to loosely align (Patterson et al, 2023). The type of aggregation is determined according to the economic sector of the borrower.

The results show that expected losses are sensitive to changes in species abundance. Specifically, Chart 33 shows how much larger the expected losses would be when comparing the adverse scenarios to the best-case scenario (SSP1 x RCP2.6). Within the euro area, banks would experience 2.5 times larger expected losses under the SSP3 x RCP6.0 scenario. This number increases to almost 2.7 if we consider a more extreme scenario (SSP5 x RCP8.5). Chart 33 also shows how the magnitude of the greater expected losses differs across euro area Member States. Depending on the scenario considered, the banking sectors of Slovakia, Ireland and Germany are likely to experience far greater expected losses due to the depletion of species abundance. Conversely, banks from Estonia and Malta tend to be less sensitive to species abundance as a proxy for biodiversity intactness. Note that supply chain dependency appears to make a significant contribution to the greater losses, implying that overseas biodiversity loss may also be important for the euro area financial system.

Chart 33

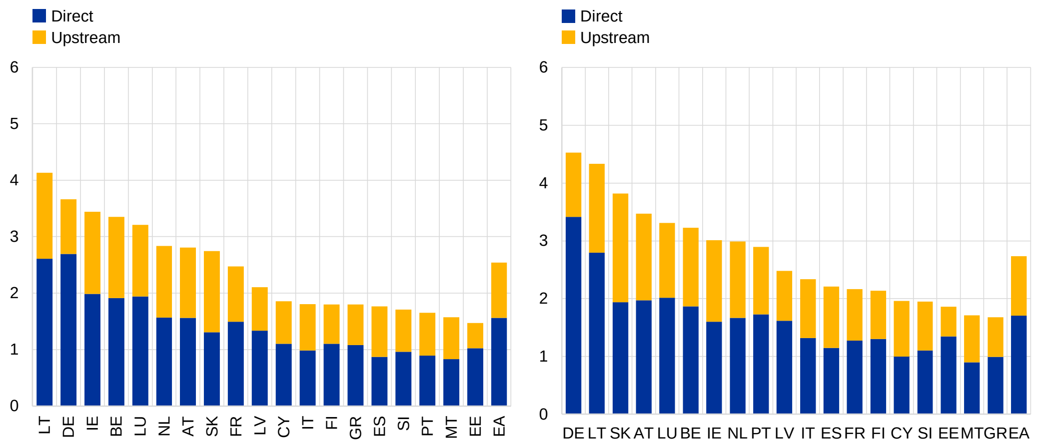
Sensitivity of bank credit portfolios to possible future changes in species abundance

a) Regional rivalry scenario (SSP3 x RCP 6.0) as worst-case

(Ratio of changes in expected losses between worst and best-case scenario)

b) Fossil-fuelled scenario (SSP5 x RCP 8.5) as worst-case

(Ratio of changes in expected losses between worst and best-case scenario)



Source: Ceglar et al. (2023a).

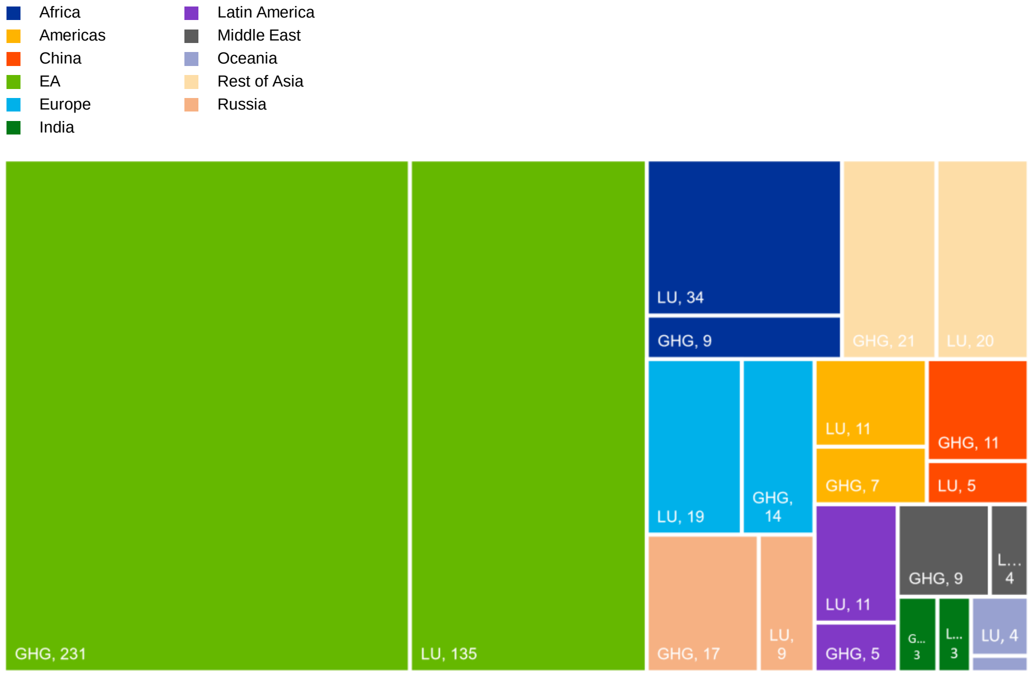
Notes: Ratio of changes in expected losses between worst-case scenario (either SSP3 x RCP6.0 or SSP5 x RCP8.5) and best-case scenario (SSP1 x RCP2.6). The scenarios are calibrated for the year 2050, therefore the expected losses should be considered as cumulated from year 2021 to 2050. Expected losses are initially computed at borrower-lender level using mean species abundancy (GLOBIO) changes as the shock. The shock is then multiplied by the dependency score of the borrower, computed using ENCORE and EXIOBASE and the uncovered amount of the loan issued to the borrower. The results are aggregated at a country level using the amount of loans as weights.

As a proxy for transition risk, we estimate the impact of euro area NFCs on nature (Ceglar et al., 2023b). This is achieved by measuring the impact of firms on nature using GLOBIO, relying on mean species abundance (MSA) as a crude proxy for the state of nature. Among the multiple anthropogenic pressures, land use and climate change are the two main pressures we consider in our analysis. The impact that a certain economic activity has on nature is measured using the environmental categories mapped in EXIOBASE.

Overall, euro area NFCs generate an impact on nature comparable to the loss of 582 million hectares of "pristine" nature worldwide (Ceglar et al., 2023b) (Figure 22). This measure is static, in the sense that it represents the (accumulated) biodiversity footprint of these firms up to 2021. The footprint is largely concentrated in Europe, where euro area firms have a direct impact on biodiversity, although they also generate a global impact when they import intermediate goods from abroad.

Figure 22
Biodiversity footprint of euro area firms

(Dec. 2021, Million MSA.ha.yr)



Source: Ceglar et al. (2023b), based on AnaCredit, EXIOBASE, Orbis, iBach and Schipper et al. (2020).
Notes: Local and global biodiversity loss caused by euro area non-financial corporations (NFC). Biodiversity losses abroad are allocated to the euro area to the extent that euro area NFCs require intermediate inputs outsourced abroad. MSA losses are computed considering GHG emissions and land used (LU) in the production of goods. MSA losses are first computed for each unit of production using EXIOBASE and GLOBIO and then multiplied by the NFC's revenue (Orbis).

5.2.3 Dependencies and impacts of EU (re)insurers on ecosystem services

The dependency or impact on nature of the (re)insurance sector is indirect. Through its direct operations, the (re)insurance industry neither has a heavy impact on nature nor consumes many natural resources compared to other sectors. (Re)insurers will thus mostly experience indirect nature-related risks through their investments and liabilities in the form of:

- **Nature-related transition risk:** misalignment of the asset and liabilities portfolios of (re)insurers with developments (policy, technological, legal, consumer preferences) aimed at reducing or reversing damage to nature can result in increased counterparty defaults or declining asset values (market risk) for their investments, and carries the risk of mispricing and higher claims (underwriting risk). For example, due to the "tightening" (increase) of legal requirements for due diligence or strict liability for environmental damage, transition risks may materialise in liability, credit and suretyship insurance.

- **Nature-related physical risk:** the materialisation of damage to nature as well as changes in natural stock and flows can cause losses on investments or higher insurance liabilities. Where insured goods or activities suffer nature-related damage, insurers may face an increasing number of claims involving significant amounts. For instance, this might occur in relation to property and business interruption insurance or crop insurance.

Our assessment of the extent to which the investments of EEA insurers are dependent on ecosystem services builds on the methodology developed to assess the exposure of the banking sector (Section 5.2.2). The exposures in scope were insurers' direct investments in corporate bonds and equity, amounting to €2.3 trillion (approximately 27% of total assets). Due to the level of data granularity required, indirect exposures via investment funds could not be assessed. When available, assets were mapped at four-digit NACE sector level. Due to data quality constraints, assets were sometimes grouped at higher levels of aggregation. Of the assets classified as highly dependent on at least one ecosystem service, about half could matched only at higher levels of aggregation, with 23% at top-level NACE (i.e. letter code). The results for assets highly dependent on at least one ecosystem service could thus be considered an upper bound – i.e. the most conservative estimate – for the direct exposures of insurers, given the prudent approach employed in aggregating to higher-level NACE sectors.

Approximately 31% of investments in corporate bonds and equity among EEA (re-)insurers are in economic activities that are highly dependent on at least one ecosystem service (Chart 34). Compared to direct dependencies only[180], accounting also for upstream dependencies along the supply chain increases the materiality to a medium dependency on at least one ecosystem service for almost half the portfolio, while the highly dependent share increases only slightly. The main exposures within portfolios of corporate securities are towards surface and ground water, as well as flood and storm protection. Insurers invest a large part of their portfolio (approximately 48%) in securities issued by financial firms, which also make up the largest part of the exposures with a medium dependency on at least one ecosystem service. As the methodology relies on a mapping to the sector of economic activity and its value chain via input-output tables, the indirect dependency on ecosystem services through an investee banks' loan book might not fully be captured. When excluding investments towards financial firms, out of the remaining portfolio of non-financial corporations approximately 59% are highly dependent on at least one ecosystem service.

[180] Box 1.1 in ***Financial Stability Report June 2023*, EIOPA, 2023.**

Chart 34

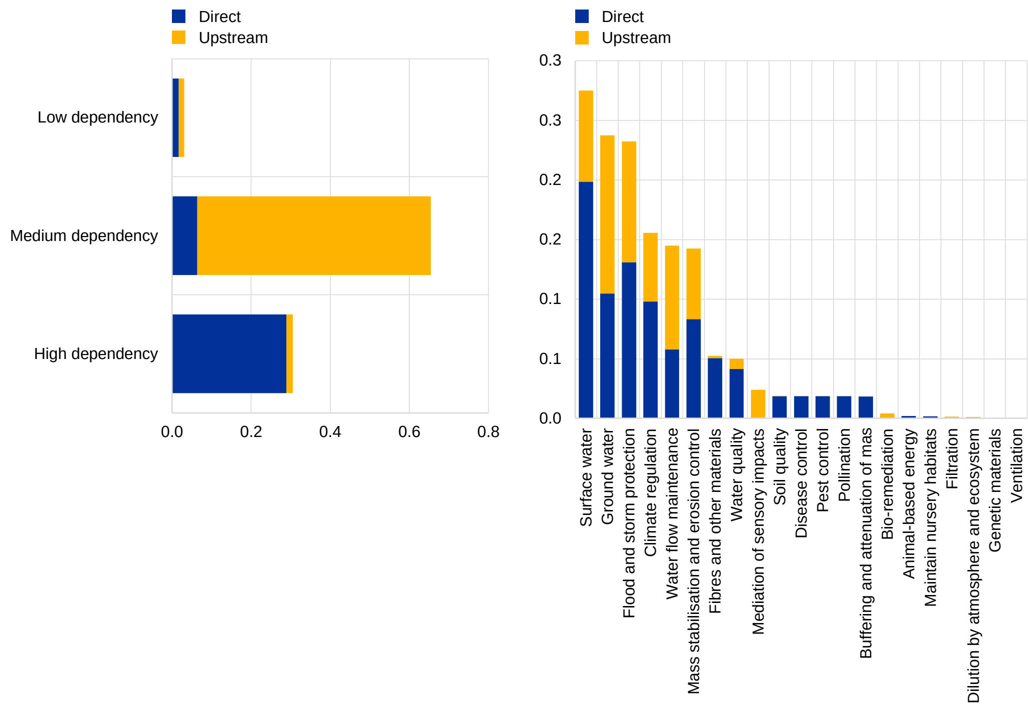
Exposures of insurers' direct corporate bond and equity investments to ecosystem services

a) Maximum dependency on ecosystem services

(December 2022, share of total direct investments in corporate bonds and equity)

b) Ecosystem services with at least high dependency

(December 2022, share of total direct investments in corporate bonds and equity)



Sources: ECB and EIOPA calculations, based on SII group QRT S.06.02 and ENCORE database.
Notes: High dependency when materiality score >=0.8; medium when <0.8 and >=0.6; and low when <0.6 and >=0.4 (panel a). Panel b) shows materiality scores >=0.7. An investment is labelled as highly dependent when the issuing firm has a sufficiently high direct dependency score (blue bar) or sufficiently high dependency when also taking into account possible supply chain linkages (yellow bar).

Box 7

Dependency on biodiversity of syndicated loans among European lenders[181]

European lenders are found to be exposed to biodiversity risk through their international lending strategies as well as through how this investor information is reflected in loan pricing. We rely on dedicated datasets on syndicated loans and an indicator on exposure to biodiversity by borrowing firms. The syndicated loans market is commonly used to measure bank lending policies and their effects. Despite comprising only a fraction of banks' total lending, syndicated loans constitute an essential source of unrestricted large-scale credit to non-financial firms by overcoming the balance sheet constraints of a single bank. A syndicated loan is offered by a syndicate of multiple creditors,

181 This box is based on Becker et al. (2023).

mainly commercial banks and firms, which issue a loan agreement to one borrower[182], i.e. a firm or a sovereign. This comes with a number of advantages. On the one hand, a small bank can take on the role of a creditor towards a large borrower, while on the other, syndication reduces the concentration of risk stemming from individual borrowers with more pronounced risk profiles by pooling it and distributing the exposure over a greater number of lenders. This allows each lender to diversify risk across the range of borrowers and their geographies. A typical characteristic of the syndicated loan market is the long maturity of the contracts, and therefore the long-term risk throughout which projected biodiversity exposure plays a non-negligible role.

We use two datasets to illustrate how biodiversity exposure affects syndicated loans: a lender-centric one (1st dataset) and a borrower-centric one (2nd dataset). The first dataset of lender scores at the country level covers 330 lenders with 10,062 tranches from 2020 to 2022. The United Kingdom, France and Germany are the three countries most heavily involved in this market.[183]

Our examination is based on granular data retrieved from the private data provider Refinitiv on syndicated loans extended by lenders located in one or other of the EU-27 countries or in the United Kingdom, and issued in favour of global borrowers. We complement the loan data inputs with biodiversity information from MSCI.[184] More precisely, we rely on a qualitative indicator to capture the extent to which a company's business is dependent on and sensitive to nature. Since the indicator is location-specific, a borrower may have different levels of biodiversity sensitivity depending on where its branches are domiciled. To calculate a "biodiversity dependency score" for each borrower, or borrower score for short, we aggregate the indicator values by computing a weighted average based on the size of the economic activity of the borrower across regions.185 As the nature-related risks of borrowing companies may be transmitted to their financing institutions, the final lender scores are estimated by weighing in the exposure and volume of credits granted to different debtors.

Figure A shows that syndicated lenders in Germany, France, Luxembourg, the Netherlands, Spain and the United Kingdom have the highest exposure to biodiversity via borrower dependency. Comparing the size of loan syndications, we find that the countries more exposed to biodiversity risk are broadly those in which the syndicated loan market is more developed. Indeed, the United Kingdom, France, Germany and Spain represent almost 75% of our sample, and this figure climbs to 90% when we include the Netherlands and Italy. Since we are considering only the fraction of syndicated loans and not the entirety of international financial flows, it is worth noting that a country presenting high biodiversity dependency according to our results does not automatically make it a potential systemic risk for the European Union. Hungary, for instance, falls in the higher range of biodiversity dependency, yet it reports an under-proportional total of six tranches offered by syndicates in the observed period. Arguably, national or European regulators would be capable of controlling the spillover effects caused by a biodiversity shock transmitted to Hungary via the syndicated loans market. Meanwhile, the United Kingdom, as a key actor on the global financial stage, represents more than 27% of the observed sample and is conspicuously more strongly

182 Syndicated loans are multilateral and might diverge in terms of maturity and purpose from bilateral loans (which have only one creditor).

183 They cover 24.96%, 25.58% and 16.38% respectively of the total volume of the syndicated loan market during the sample period.

184 See **https://www.msci.com/our-solutions/climate-investing/biodiversity-sustainable-finance**.

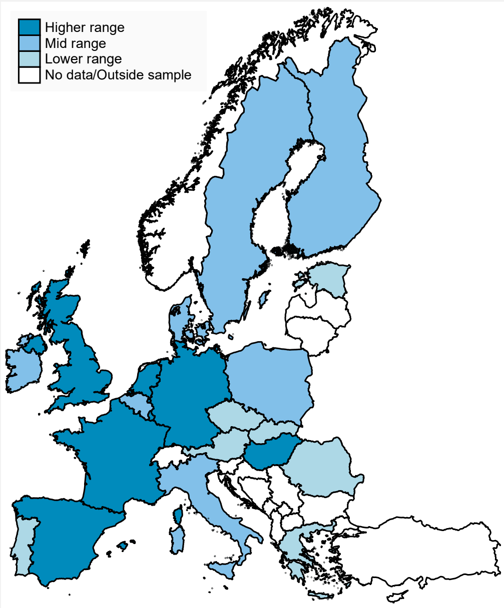
185 Borrowers' economic activities are quantified through operating revenues retrieved from the Orbis database.

exposed to biodiversity risk. This may raise concerns of significant financial spillovers to EU countries from outside the EU. The outcome suggests that coordination between national financial regulators and authorities is crucial to tackle the potential financial repercussions of natural degradation.

Figure A

Biodiversity dependency in the syndicated loan market by lender score (EU27+1)

(score ranging from 1 to 3)



Sources: Eurostat, MSCI, Orbis, Refinitiv and authors' own calculations.

The second dataset (borrower score) covers 209 lenders with a total of 5,390 tranches from 2017 to 2022.[186] The sampling of this dataset relies on a relative time dimension: either a loan was activated prior to the issuance of the biodiversity score assigned to that borrower, or the biodiversity score was available before the tranche was activated.[187] Loan pricing over the cross-section of borrowers can be compared both before and after the score is introduced for each borrower. Exploiting this variation at the tranche level, we run inferential statistics and find that the biodiversity score of borrowers both positively and significantly raises the tranche's margin (Chart **A**). The graph visualises the mean of the margin charged for loans, conditional on the model's covariates, over the full range of borrower scores for biodiversity dependency. Meanwhile, accounting for the characteristics of the syndicated loans, and the lenders and the borrowers in our control vector – particularly the world region where borrowers operate – significantly increases the pricing effect. This result suggests that investors not only process known borrower-specific traits (like where it operates) into the lending rate, but also absorb the growing wealth of investor information available from data providers on nature-related risks as a factor in loan pricing, thus charging a "biodiversity

186 Even though the sample period for the 2nd dataset covers three more years than the 1st dataset, fewer observations remain due to more variables considered in the estimation, i.e. row-wise deletion of covariates with missing values.

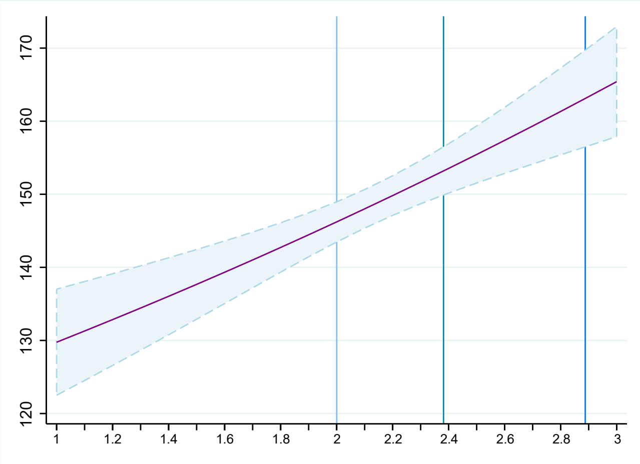
187 MSCI started to compute the biodiversity score for 20% of its borrowers in 2020, enlarging its coverage in 2021 and 2022.

premium" to borrowers more dependent on natural capital. Other location-specific aspects like regulation could increase this spillover effect.

Chart A

Pricing of syndicated loans and biodiversity exposure by borrower score (global)

(basis points)



Sources: MSCI, Orbis, Refinitiv and authors' own estimations.

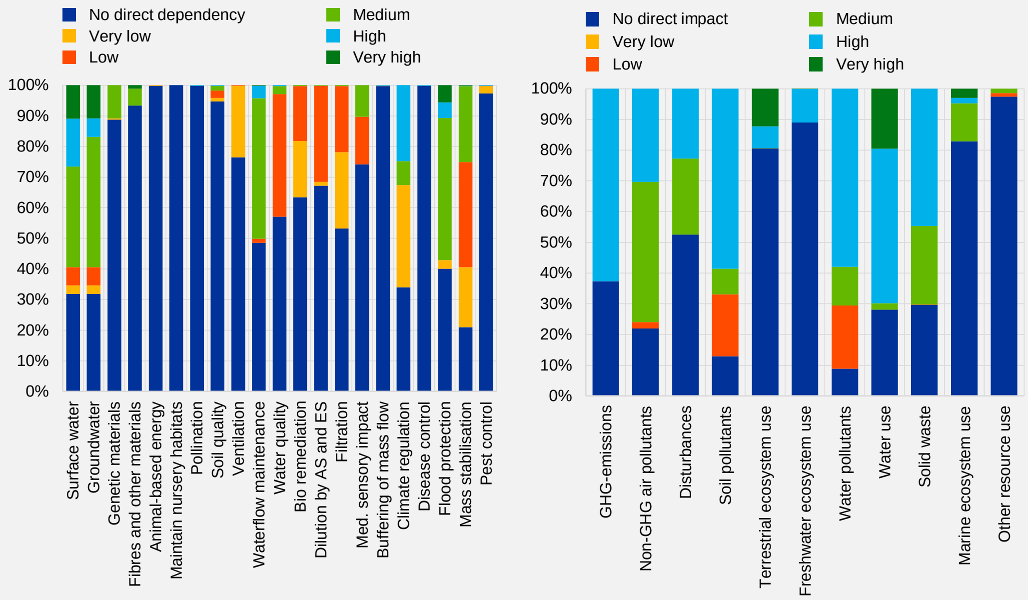
Box 8
Dependencies and impacts of the European equity market on ecosystem services[188]

An assessment of European stock market portfolios for risks arising due to the degradation of ecosystems and concomitant biodiversity loss, otherwise known as nature-related financial risks, is an essential complement to the assessment of bank loan and insurer portfolios. Despite large listed companies being highly diversified in their business segments and geographical locations, even a local degradation of ecosystems could result in the need to relocate production sites or adjust economic activities, thus affecting the profitability of a firm. Similar to climate risks, economic activities depend on ecosystem services but can also adversely affect ecosystems and biodiversity. Dependencies reflect not only vulnerabilities to ecosystem degradation, but also physical hazards. At the same time, restrictions on negative externalities of production or resource use, commonly referred to as transition risks, have the potential to constrain production.

[188] This box is based on Hirschbuehl (2023), "The role of ecosystem- and biodiversity-related factors in the European stock market", *JRC Working Paper*, forthcoming.

Chart A

Portfolio shares of nature-related financial risk exposures



Source: Datastream, ENCORE and authors' calculations.
Notes: Exposures are derived from 2021 business segment net sales. High and very high materiality can imply production failure. ENCORE risk exposures are approximations, not measurements, and hence should be interpreted with caution.

Data gaps are a major problem when it comes to analysing ecosystem service-related risks, and finding a suitable framework for structuring all relevant dimensions from an economic perspective at the level of the portfolio or firm is equally challenging. Chart A displays nature-related financial risk exposures at different materiality rating levels for ecosystem service dependencies[189] (panel a) and impacts (panel b) for a European stock market portfolio. The economic activities of each firm are approximated by business segment net sales. Ecosystem dependencies are grouped according to their economic rationale into four groups: (i) direct physical input; (ii) enabling the production process; (iii) mitigating direct impact; and (iv) protecting from disruption. The first and last categories are the most relevant from an economic standpoint. Water scarcity, if growing beyond regional scope, has the potential to interrupt production in water-intensive industries. Water is also relevant from an impact (transition risk) perspective, as regulators could restrict water abstraction that is not aligned with a sustainable water cycle. While there is no formal grouping for impacts on ecosystem services, we group these into five categories, namely: (i) air; (ii) soil; (iii) water use and pollution; (iv) waste; and (v) resource use. From an economic perspective, in addition to GHG

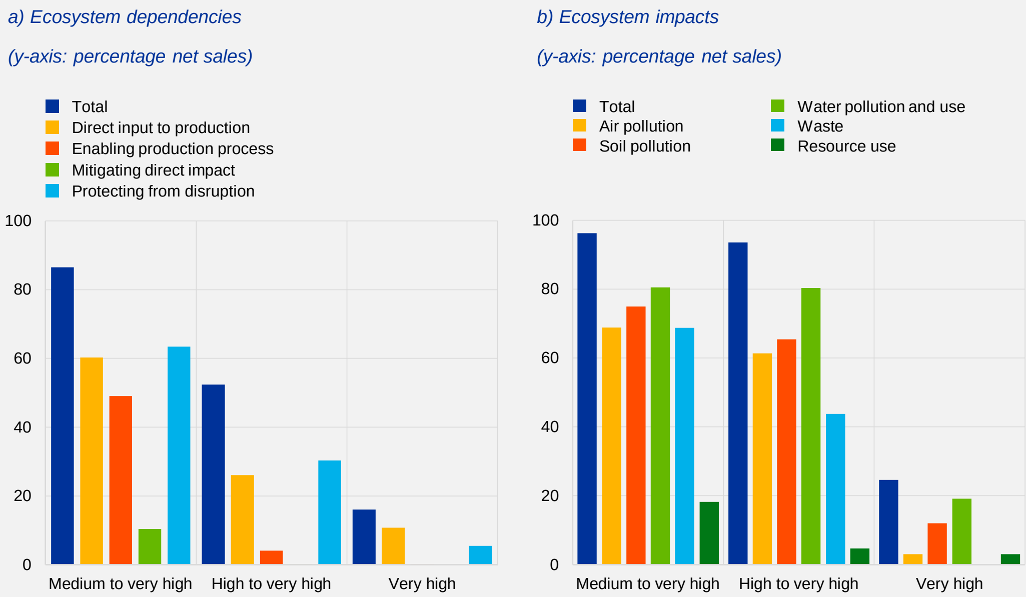
[189] It uses the ENCORE methodology, which maps economic sectors to ecosystem services without accounting for geolocational differences.

emissions, noise disturbances, water use and pollution, and waste might become subject to tighter regulation.[190]

To better understand the relative importance of ecosystem services, Chart B below shows the share of net sales exposed to one or more nature-related risks, grouped in three categories of different materiality ratings. In total, ~85% of sales in the portfolio are exposed to one or more nature-related risks with a medium to very high materiality, compared to ~15% with very high materiality. Notably, the two main categories – direct inputs and protecting from disruption – are of significant importance across all levels of materiality ratings. Panel b also shows the importance of ecosystem impact risks.[191]

Chart B

Share of portfolio exposed to ecosystem service dependency (left) and impact (right) risk exposures for different materiality ratings



Source: Datastream, ENCORE and authors' calculations.
Notes: The chart displays 2021 net sales exposed to at least one ecosystem service risk per total or per category with a certain materiality normalised by total sales. High and very high materiality ratings can imply production failure

Following the enactment of the SFDR, many companies are already disclosing some data related to their impact on nature. Within the selected sample of firms, Chart C below shows the relative share of companies (blue) or sales (yellow) to have implemented a policy, e.g. on emissions or

190 On the impact side, this holistic mapping could be refined by using pollution data, as the combination with ReCIPe end-point assessments would allow us to aggregate those into a single metric of biodiversity (species) loss or ecosystem service pressure. Similarly, ecosystem dependency exposures as described by the NCFA/UNEP-WCMC (2018) might be used as a junction point to link a company via its location to regional exposures to natural hazards (floods, soil erosion or droughts) or interruptions in ecosystem services.

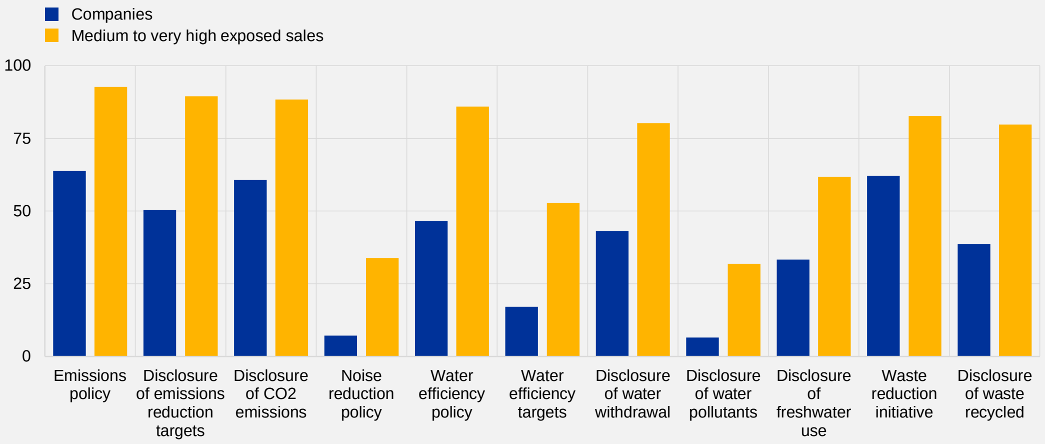
191 The approach can be utilised to calculate firm-level risk exposure scores that could be used to construct high and low risk exposure portfolios, allowing for an evaluation of the portfolios present in asset pricing models. Early results suggest that low exposures to pollution and resource use risks that have received attention in recent years (air emissions, waste, and resource use) have been outperforming their high-exposure counterpart portfolios since 2018.

water efficiency, or to have disclosed information on targets, pollution and resource use data. While technological constraints might pose limitations to the feasibility of pollution reduction, existing data – despite disclosure gaps – indicate a broad awareness of nature-related transition risks and allow for risk assessment given pollution targets. Further initiatives will be undertaken to fill the data disclosure gap for nature-related financial risks.[192]

Chart C

Companies and sales with policies or data disclosure on nature-related transition risks

(percentage share)



Sources: Datastream, ENCORE and authors' own calculations.
Notes: The chart displays data disclosure in 2021 for all companies in the portfolio on policies and pollution, normalised by the amount of companies (blue). Medium to very high risk-exposed sales (yellow) are calculated for GHG emissions under the emissions policy, for disclosure of emissions reduction targets, for disclosure of CO2 emissions, for disturbances relating to the noise reduction policy, for water use under the water efficiency policy, for water efficiency targets, for disclosure of water withdrawal, for disclosure of water pollutants, for disclosure of freshwater use, and for solid waste under the waste reduction initiative, and lastly for disclosure of total waste recycled.

5.3 Nature-related initiatives in EU jurisdictions

The March 2022 NGFS-INSPIRE report on central banking in the biosphere[193] made a case for the potential relevance of nature-related risks to financial stability and called for further action from central banks and supervisors. The recommended actions were as follows: (i) Recognise biodiversity loss as a potential source of economic and financial risk and commit to developing a response strategy; (ii) Build the skills and the capacity to analyse and address biodiversity-related financial risks; (iii) Assess the degree to which financial systems are exposed to biodiversity loss; (iv) Explore options for supervisory actions on managing biodiversity-related risks and minimising negative impacts on ecosystems; and (v) Devote efforts to building the necessary financial architecture for mobilising investment for a biodiversity-positive economy, including by

192 See Taskforce on Nature-related Financial disclosures, *Recommendations of the Taskforce on Nature-related Financial Disclosures*, September 2023.

193 "Central banking and supervision in the biosphere: An agenda for action on biodiversity loss, financial risk and system stability", *NGFS Occasional Paper*, March 2022.

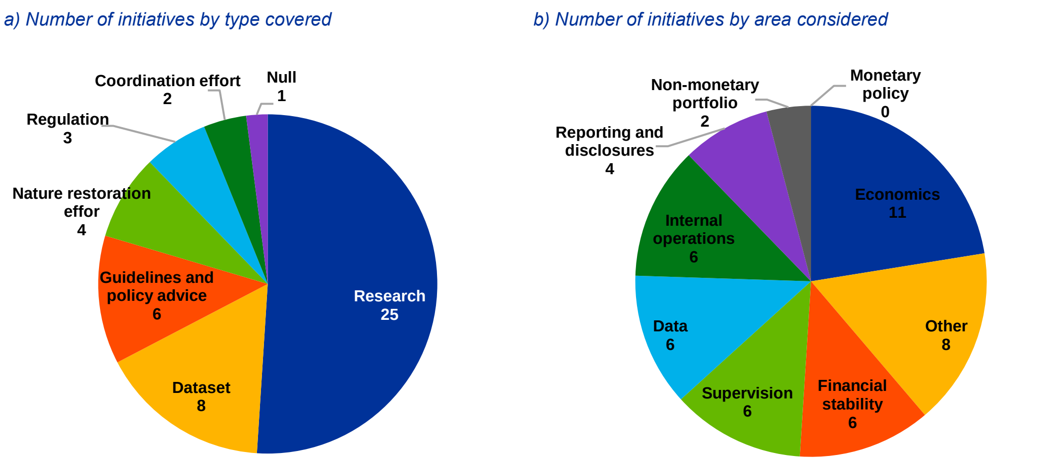
considering how central banks' own operations should be conducted in the context of biodiversity loss.

An analysis of the initiatives undertaken by the EU members of the NGFS (largely central banks and supervisors) reveals that nature-related initiatives are still at an initial stage.[194] Most of the initiatives are research initiatives (Chart 35, panel a), which is understandable given the need to develop new internal capacity, knowledge and methodologies. At the same time, research papers are key to raising awareness. De Nederlandsche Bank (DNB), Banque de France (BdF) and the ECB have already began to assess how euro area financial systems are exposed to nature-related risks by considering both the impact and the dependency of firms and banks to ecosystem services. The lack of reliable data and well-established methodologies contributes to a scarcity of other types of initiative, including policy advice. The second largest type of initiatives relates to the establishment of internal datasets, aimed at addressing current gaps that might ultimately pave the way for further studies.

Most of the initiatives relate to economics, financial stability, and banking supervision (Chart 35, **panel b)**. The focus on these areas might stem from the fact that there is more data available and/or they are subject to less restrictive modelling constraints, at least for initial explorative studies. Current endevours seem to be focused on financial stability assessments through an exposure analysis, i.e. a dependency and impact assessment. For the time being, our economic models appear not robust enough to factor nature into monetary policy assessments. It is therefore understandable that resources should be spent now on the economic modelling of nature risks before expanding to other areas.

Chart 35

Characteristics of the initiatives of EU central banks and regulators



Source: ECB.

Note: Number of initiatives related to nature-related risks by type and area considered. A total of 17 institutions were surveyed mapping 49 distinct initiatives.

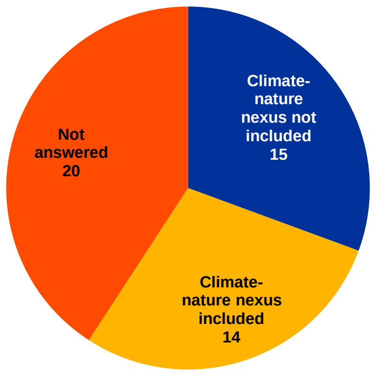
194 The initiatives were identified through a voluntary survey.

While science has made clear that climate change is inextricably intertwined with nature degradation, capturing the relationship between climate change and other environmental degradations remains a challenge. Chart 36, left and right panels, shows that EU central banks and supervisors have difficulties in capturing the climate-nature nexus. Only 14 out of the 49 initiatives in scope take into account the relationship with climate change when considering nature-related risks.

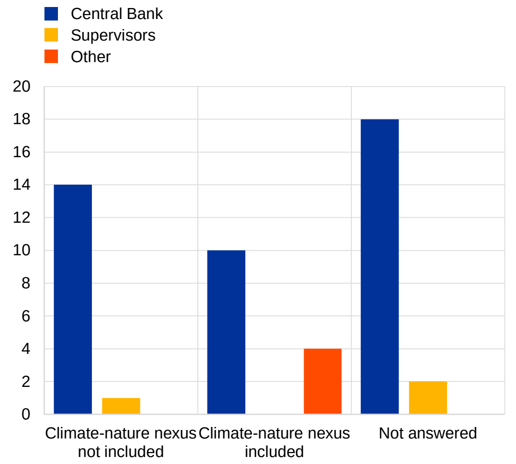
Chart 36

Climate-nature nexus

a) Number of initiatives by answer



b) Number of initiatives by institution



Source: ECB.

Notes: Number of initiatives related to nature-related risks. Here central banks include also institutions that combine central banking and supervisory functions. A total of 17 institutions were surveyed mapping 49 distinct initiatives.

6 Conclusions

This report lays out three interrelated macroprudential frameworks for climate risks. These include respective frameworks for: (i) surveillance, or gathering evidence on monitoring and assessing climate-related risks to financial stability; (ii) macroprudential policy, or providing a strategy and operationalisation building on this evidence; and (iii) broader financial stability risks arising from nature degradation.

A surveillance framework tracks financial stability risks emanating from climate change shocks, along with exposures to these shocks and their interplay with financial risk. There is a growing prospect of climate-related shocks as time elapses, from both transition and physical risks. While economic and financial exposures to such climate risk are heterogeneous, some concentrations are prominent, notably in the corporate and mortgage lending portfolios of banks. Bank loans to firms in high-emitting economic sectors are around 75% more emissions-intensive than shares in economic activity, and high-emitting households typically comprise 60-80% of total mortgage borrowers in euro area countries. Financial risk may arise through the interplay of climate exposure with financial vulnerabilities. Scenario analysis suggests strong energy transition needs over the next decade, with the prospect of compound climate and financial shocks. In this vein, systemic risk may arise in parallel to the climate transition (or lack thereof), notably from a combination of compound climate shocks, scope for economic spillovers – including through trade linkages, financial amplification and contagion, as well as contingent risk transfer to governments.

A second framework leverages evidence on financial stability risks as the basis for a macroprudential strategy for climate change, alongside a preliminary operational design based on existing instruments. Within a broader set of policies to mitigate climate change and support adaptation, prudential policies have a role to play in addressing associated financial risks. Macroprudential policy would complement various microprudential initiatives, focusing on reducing risk build-up, increasing resilience and lessening the prospect and materialisation of tail events. An important element is managing the risks faced by banks as key lenders to the economy – whether the aggregate risk to the banking sector, or relative risk in the form of risk concentrations – with a systemic risk buffer or concentration limits flexible enough to potentially target specific climate risks. Taking a system-wide view beyond banks, such measures directed at banks can be complemented by measures to contain risk for borrowers, alongside initiatives to address information and insurance protection gaps in the area of non-bank financial intermediation. Irrespective of the specific macroprudential approach taken, a holistic approach, aimed at being consistent with macroprudential policies, is needed.

In addition to climate-related risks, the report contains a third framework taking a first look at nature-related risks. In addition to a conceptual framework for tackling nature-related risk, the report contains a quantitative exploration of exposure analyses. According to preliminary estimates, 75% of corporate loans among euro area banks and 31% of investments in corporate bonds and equity among EEA insurers are in sectors that are highly reliant on at least one service provided by nature.

These frameworks are intended as a legacy of this ESRB/Eurosystem Project Team. Going forward, these frameworks, alongside a deeper understanding of climate-related risks to financial stability, will be integrated into ongoing risk surveillance and macroprudential policy assessments.

References

Acharya, V., T. Johnson, S. Sundaresan and T. Tomunen (2022). “Is physical climate risk priced? Evidence from regional variation in exposure to heat stress”, NBER working paper 30445.

Aiello, M.A. and Angelico, C. (2023), “Climate change and credit risk: The effect of carbon taxes on Italian banks’ business loan default rates”, Journal of Policy Modeling, Vol. 45, Issue 1, pp. 187-201.

Alessi, L. and Battiston, S. (2022), “Two sides of the same coin: Green Taxonomy alignment versus transition risk in financial portfolios”, International Review of Financial Analysis, Vol. 84.

Alessi, L. and Battiston, S. (2023), “Taxonomy alignment and transition risk: a country-level approach”, Working Papers in Economics and Finance, No 12, European Commission – Joint Research Centre.

Alessi, L., Battiston, S. and Kvedaras, V. (2023), “Over With Carbon? Investors’ Reaction to the Paris Agreement and the US Withdrawal”, Journal of Financial Stability, forthcoming.

Allen, T., Boullot, M., Dées, S., de Gaye, A., Lisack, N., Thubin, C., Wegner, O., (2023). “Using Short-Term Scenarios to Assess the Macroeconomic Impacts of Climate Transition”, Banque de France, Working Paper 922.

Alogoskoufis, S., Dunz, N., Emambakhsh, T., Hennig, T., Kaijser, M., Kouratzoglou, C., Muñoz, M.A., Parisi, L. and Salleo, C. (2021), “ECB economy-wide climate stress test – Methodology and results”, Occasional Paper Series, No 281, ECB, September

Ando, A., Fu, C., Roch, F., and Wiriadinata, U. (2023), “How Large is the Sovereign Greenium?”, IMF working Paper No. 2023/080.

Arevalo, P., Gagliardi, N. and Pamies, S. (2022), “The Fiscal Impact of Extreme Weather and Climate Events: Evidence for EU Countries”, Discussion Papers, No 168, European Commission, July.

Banco de Portugal (2022), “Box 5: Exposure of the banking system to climate transition risks inherent in the housing loan portfolio – exploratory analysis”, Financial Stability Report, November.

Barasinska, N., Ludwig, J. and Vogel, E. (2021), “The impact of borrower-based instruments on household vulnerability in Germany”, Discussion Papers, No 20, Deutsche Bundesbank, July.

Barbaglia, L., Fatica, S. and Rho, C. (2023), “Flooded credit markets: physical climate risk and small business lending”, Working Paper, forthcoming, European Commission – Joint Research Centre.

Basel Committee on Banking Supervision (2021), “Climate-related risk drivers and their transmission channels”, Bank for International Settlements, April.

Basel Committee on Banking Supervision (2022), "**Principles for the effective management and supervision of climate-related financial risks**", Bank for International Settlements, June.

Batten, S. (2018), "Climate change and the macro-economy: a critical review", Staff Working Papers, No 706, Bank of England, January.

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F. and Visentin, G. (2017), "A climate stress-test of the financial system", Nature Climate Change, Vol. 7, pp. 283-288.

Becker, A., Di Girolamo, F.E. and Rho, C. (2023), "Loan pricing and biodiversity exposure: nature-related risk spillovers to the financial sector", JRC Working Paper Series in Economics and Finance No. 2023/11, JRC135774.

Bellia M., Di Girolamo, F.E., Pagano, A. and Papadopoulos, G. (2023a), "Banks and flood risk: the case of Germany", JRC Working Papers in Economics and Finance, 2023/13, European Commission, Ispra, Italy, 2023.

Bellia, M., Di Girolamo, F.E., Pagano A. and Petracco Giudici, M. (2023b), "Flood protection gap: evidence for public finances and insurance premiums", JRC Working Papers in Economics and Finance, No 10, European Commission – Joint Research Centre.

Bellia, M., Fatica, S., Panzica, R. and Tiozzo Pezzoli, L. (2023c), "The importance of being green: climate news and sovereign spreads", Working Paper, forthcoming, European Commission – Joint Research Centre.

Belloni, M., Kuik, F. and Mingarelli, L. (2022), "Euro Area banks' sensitivity to changes in carbon price", Working Paper Series, No 2654, ECB, Frankfurt am Main, March.

Berestycki, C., Carattini, S., Dechezleprêtre, A. and Kruse, T. (2022), "Measuring and assessing the effects of climate policy uncertainty", OECD Economics Department Working Papers, No 1724, Organisation for Economic Co-operation and Development, August.

Berg, F., Heeb, F. and Kölbel, J.F. (2022), "The Economic Impact of ESG Ratings", May.

Berg, T. (2010), "The term structure of risk premia: new evidence from the financial crisis", Working Paper Series, No 1165, ECB, Frankfurt am Main, March.

Bernanke, B. (1983), "Nonmonetary Effects of the Financial Crisis in the Propagation of the Great Depression", The American Economic Review, Vol. 73, No 3, pp. 257-276.

Billio, M., Costola, M., Pelizzon, L. and Riedel, M. (2022), "Buildings' Energy Efficiency and the Probability of Mortgage Default: The Dutch Case", The Journal of Real Estate Finance and Economics, Vol. 65, Issue 3, pp. 419-450.

Bolton, P., Buchheit, L., Gulati, M., Panizza, U., Weder di Mauro, B. and Zettelmeyer, J. (2022), "Climate and Debt", Geneva Reports on the World Economy, No 25, International Center for Monetary and Banking Studies (ICMB) and Centre for Economic Policy Research (CEPR).

Bose, U., Gregori, W.D. and Martinez-Cillero, M. (2023), “Does Green Transition promote Green Innovation and Technological Acquisitions?”, Working Papers, No 5, Banco de Portugal, March.

Busch, T., Bruce-Clark, P., Derwall, J., Eccles, R., Hebb, T., Hoepner, A., Klein, C., Krueger, P., Paetzold, F., Scholtens, B. and Weber, O. (2021), “Impact investments: a call for (re)orientation”, SN Business & Economics, Vol. 1, Issue 2, pp. 1-13.

Calice, P., Diaz Kalan, F. and Miguel, F. (2021), “**Nature-Related Financial Risks in Brazil**”, Policy Research Working Papers, No 9759, World Bank, August.

Caloia, F. and Jansen, D.J. (2021), “Flood risk and financial stability: Evidence from a stress test for the Netherlands”, Working Papers, No 730, De Nederlandsche Bank, November.

Canals-Cerdá, J.J. and Roman, R. (2021), “Climate Change and Consumer Finance: A Very Brief Literature Review”, Discussion Papers, No 21-04, Federal Reserve Bank of Philadelphia, October.

Ceglar, A., Boldrini, S., Lelli, C. Parisi, L. and Heemskerk, I. (2023a), “Living in a world of disappearing nature: the implications for financial stability”, Occasional Paper Series, forthcoming, ECB, Frankfurt am Main.

Ceglar A., Boldrini, S., Lelli, C., Parisi, L. and Heemskerk, I. (2023b), “Are we contributing to disappearing nature? The impact of the European economy and financial system on biodiversity”, Occasional Paper Series, forthcoming, ECB, Frankfurt am Main.

Clayton, J., Devaney, S., Sayce, S. and van de Wetering, J. (2021), “Climate Risk & Commercial Property Values: A review and analysis of the literature”, United Nations Environment Programme Finance Initiative.

Coelho, R. and Restoy, F. (2023), “Macroprudential policies for addressing climate-related financial risks: challenges and trade-offs”, FSI Briefs, No 18, Financial Stability Institute, Bank for International Settlements, April.

Correa, R., He, A., Herpfer, C. and Lel, U. (2022), “The rising tide lifts some interest rates: climate change, natural disasters, and loan pricing”, International Finance Discussion Papers, No 1345, Board of Governors of the Federal Reserve System, June.

Crisóstomo, R. (2022), Measuring Transition Risk in Investment Funds, CNMV Working Papers No. 81.

Dees, S. (2017), “The role of confidence shocks in business cycles and their global dimension”, International Economics, Vol. 151, pp. 48-65.

De Guindos, L. (2023), “Need for speed on the Road to Paris”, ECB Blog, 6 September.

De Jonghe, O., Dewachter, H. and Ongena, S. (2020), “Bank capital (requirements) and credit supply: Evidence from pillar 2 decisions”, Journal of Economic Finance, Vol. 60.

De Lisa,R., Zedda,S., Vallascas,F., Campolongo,F., and Marchesi,M. (2011), "Modelling deposit insurance scheme losses in a Basel 2 framework", Journal of Financial Services Research,40 (3):123–141.

Delta Programme Commissioner (2021), "Staying on track in climate-proofing the Netherlands", Ministry of Infrastructure and Water Management.

Di Virgilio, S., Faiella, I., Mistretta, A. and Narizzano, S. (2023), "Assessing credit risk sensitivity to climate and energy shocks", Banca d'Italia.

Dixit, A. and Pindyck, R. (1994), Investment under Uncertainty, Princeton University Press.

Dutta, P. and Dutta, A. (2021), "Impact of external assurance on corporate climate change disclosures: new evidence from Finland", Journal of Applied Accounting Research, Vol. 22, Issue 2, pp. 252-285.

Edens, B., Maes, J., Hein, L., Obst, C., Siikamaki, J., Schenau, S., Javorsek, M., Chow, J., Chan, J.Y., Steurer, A. and Alfieri, A. (2022), "**Establishing the SEEA Ecosystem Accounting as a global standard**", Ecosystem Services, Vol. 54.

Emambakhsh, T., Fuchs, M., Kördel, S., Kouratzoglou, C., Lelli, C., Pizzeghello, R., Salleo, C. and Spaggiari, M. (2023), "**The Road to Paris: stress testing the transition towards a net-zero economy**", Occasional Paper Series, No 328, ECB, Frankfurt am Main, September.

Energy Efficient Mortgages Initiative (2022), "EE and credit risk correlation: Evolution of the Basel regulation framework and its potential impact on EEM", April.

Eryzhenskiy, I., Giraudet, L.G., Segú, M. and Dastgerdi, M. (2022), "Zero-Interest Green Loans and Home Energy Retrofits: Evidence from France".

European Banking Authority (2020), **Guidelines on the appropriate subsets of exposures in the application of SyRB**, 30 September 2020

European Banking Authority (2022), "**The role of environmental risk in the prudential framework**", *Discussion Papers*, No 2, May.

European Banking Authority (2023a), "Progress report on greenwashing monitoring and supervision", March.

European Banking Authority (2023b), "Report on the role of environmental and social risks in the prudential framework", October.

European Banking Authority and European Systemic Risk Board (2023), "Macro-financial scenario for the 2023 EU-wide banking sector stress test", March.

European Central Bank (2021a), Financial Stability Review, May.

European Central Bank (2021b), "Climate risk stress test – SSM stress test 2022", ECB Banking Supervision Report, October.

European Central Bank (2021c), “Household Finance and Consumption Survey”.

European Central Bank (2021d), “The sovereign-bank-corporate nexus – virtuous or vicious?”, speech by Isabel Schnabel, January.

European Central Bank (2022a), **“2022 climate risk stress test**”, July.

European Central Bank (2022b), “Walking the talk: Banks gearing up to manage risks from climate change and environmental degradation. Results of the 2022 thematic review on climate-related and environmental risks”, November.

European Central Bank (2022c), “Carbon-related concentration risk: measurement and applications*”, Financial Stability Review*, November.

European Central Bank (2022d), Financial Stability Review, November.

European Central Bank (2023a), “**Towards climate-related statistical indicators**”, January.

European Central Bank (2023b), “Results of the 2022 supervisory assessment of institutions' climate-related and environmental risks disclosures”, April.

European Central Bank and European Insurance and Occupational Pensions Authority (2023), “**Policy options to reduce the climate insurance protection gap**”, Discussion Paper, April.

European Central Bank and European Systemic Risk Board (2020), “Positively green: Measuring climate change risks to financial stability”, Report of the Project Team on Climate Risk Monitoring, June.

European Central Bank and European Systemic Risk Board (2021), “Climate-related risk and financial stability”, Report of the Project Team on Climate Risk Monitoring, July.

European Central Bank and European Systemic Risk Board (2022), “The macroprudential challenge of climate change”, Report of the Project Team on Climate Risk Monitoring, July.

European Commission (2019), “**The European Green Deal: Striving to be the first climate-neutral continent**”, web page.

European Commission (2020), “**Farm to Fork strategy: for a fair, healthy and environmentally-friendly food system**”.

European Commission (2021), “**EU biodiversity strategy for 2030: Bringing nature back into our lives**”, May.

European Commission (2022), “**Fiscal Sustainability Report 2021**”, European Commission Institutional Papers, No 171, April.

European Commission and Energy Efficiency Financial Institutions Group (2022), “The quantitative relationship between energy efficiency improvements and lower probability of default of associated loans and increased value of the underlying assets – Final report on risk assessment”, April.

European Commission – Joint Research Centre (2023), “**Mapping and Assessment of Ecosystems and their Services**”, web page.

European Environment Agency (2020), “State of nature in the EU: Results from reporting under the nature directives 2013-2018”, EEA Reports, No 10.

European Environment Agency (2023), “**Seas and coasts**”, web page.

European Insurance and Occupational Pensions Authority (2022a), “European insurers’ exposure to physical climate change risk. Potential implications for non-life business”, May.

European Insurance and Occupational Pensions Authority (2022b), “The dashboard on insurance protection gap for natural catastrophes in a nutshell”, December.

European Insurance and Occupational Pensions Authority (2022c), “2022 IORP Climate Stress Test Report”, December.

European Insurance and Occupational Pensions Authority (2023), “Progress Report on Greenwashing”, June.

European Securities and Markets Authority (2023a), “Report on Trends, Risks and Vulnerabilities”, No 1, February.

European Securities and Markets Authority (2023b), “Progress Report on Greenwashing”, May.

European Securities and Markets Authority (2023c), “Dynamic modelling of climate-related shocks in the fund sector”, forthcoming.

European Systemic Risk Board (2022), “Review of the EU Macroprudential Framework for the Banking Sector: A Concept Note”, March.

European Systemic Risk Board (2023), “ESRB advice to the EBA on the prudential treatment of environmental and social risks”, August.

Eurostat (2015), “**Household Budget Survey**”, reference year 2015.

Eurostat (2018), “Statistics on Income and Living Conditions”.

Fache Rousová, L., Giuzio, M., Kapadia, S., Kumar H., Mazzotta, L., Parker, M. and Zafeiris, D. (2021). “**Climate Change, Catastrophes and the Macroeconomic Benefits of Insurance**”, EIOPA Financial Stability Report, July 2021.

Fahr S, M Giuzio, C Mc Sweeny Pourtalet, M Spaggiari and J Vendrell (2023), **Climate change and sovereign risk**, ECB Financial Stability Review (May).

Faiella, I. and Lavecchia, L. (2020), “The carbon footprint of Italian loans”, Occasional Papers, No 557, Banca d’Italia, April.

Faiella, I., Lavecchia, L., Michelangeli, V. and Mistretta, A. (2022), “A climate stress test on the financial vulnerability of Italian households and firms”, Journal of Policy Modeling, Vol. 44, Issue 2, pp. 396-417.

Fatica, S., Kátay, G. and Rancan, M. (2022), “Floods and firms: vulnerabilities and resilience to natural disasters in Europe”, JRC Working Papers in Economics and Finance, No 13, European Commission – Joint Research Centre.

Fatica, S., Panzica, R. and Rancan, M. (2021), “The pricing of green bonds: are financial institutions special?”, Journal of Financial Stability, Vol. 54.

Favara, G., Gao, J. and Giannetti, M. (2021), “Uncertainty, access to debt, and firm precautionary behavior”, Journal of Financial Economics, Vol. 141, Issue 2, pp. 436-453.

Ferriani, F. and Gazzani, A.G. (2022), “The impact of the war in Ukraine on energy prices: Consequences for firms’ financial performance”, October.

Feyen, L., Ciscar, J.C., Gosling, S., Ibarreta, D. and Soria, A. (eds.) (2020), “Climate change impacts and adaptation in Europe”, JRC PESETA IV final report, European Commission – Joint Research Centre.

Financial Stability Board (2022), “Supervisory and Regulatory Approaches to Climate-related Risks – Final report”, October.

Frankovic, I. (2022), “The impact of carbon pricing in a multi-region production network model and an application to climate scenarios”, Discussion Papers, Deutsche Bundesbank, No 07/2022, 4 March.

Frankovic, I., Etzel, T., Falter, A., Gross, C., Ohls, J., Strobel, L. and Wilke H. (2023). “Climate transition risk stress test for the German financial system”, Bundesbank Technical Paper 04/2023.

Gardó S., B. Hartung, M. Jarmuzek and A. Prapiestis (2021), ”**Contingent liabilities: past materialisations and present risks**”, ECB Financial Stability Review (May).

Giannetti, M., Jasova, M., Loumioti, M. and Mendicino, C. (2023), “‘Glossy Green’ Banks: The Disconnect Between Environmental Disclosures and Lending Activities”, Finance Working Papers, No 919, European Corporate Governance Institute, September.

Giannoulakis, S., Forletta, M., Gross, M. and Tereanu, E. (2023), “The effectiveness of borrower-based macroprudential policies: a cross-country analysis using an integrated micro-macro simulation model”, Working Paper Series, No 2795, ECB, Frankfurt am Main, March.

Gross, M. and Población, J. (2017), “Assessing the efficacy of borrower-based macroprudential policy using an integrated micro-macro model for European households”, Economic Modelling, Vol. 61, pp. 510-528.

Guin, B., Korhonen, P. and Moktan, S. (2022), “Risk differentials between green and brown assets?”, Economics Letters, Vol. 213.

Hantzsche, A., Lopresto, M. and Young, G. (2018), “Using NiGEM in uncertain times: Introduction and overview of NiGEM”, National Institute Economic Review, Vol. 244, Issue 1, R1-R14.

Huizinga, J., De Moel, H. and Szewczyk, W. (2017), “Global flood depth-damage functions: Methodology and the database with guidelines”, JRC Technical Reports, No 105688, European Commission – Joint Research Centre.

Heeb, F., Kölbel, J.F., Paetzold, F. and Zeisberger, S. (2023), “Do investors care about impact?”, The Review of Financial Studies, Vol. 36, Issue 5, pp. 1737-1787.

Hejlová, H., Holub, L. and Plašil, M. (2021), “Calibration of Borrower-based Macroprudential Measures for Mortgage Exposures: Rigorous Approach and Its Application to the Czech Republic”, Prague Economic Papers, Vol. 30, Issue 3, pp. 316-335.

Hiebert, P. and Monnin, P. (2023), “Climate-Related Systemic Risks and Macroprudential Policy”, INSPIRE Policy Briefing Papers, No 14, International Network for Sustainable Financial Policy Insights, Research and Exchanges, August.

Hirschbuehl, J. (2023), “The role of ecosystem- and biodiversity-related factors in the European stock market”, Working Paper, forthcoming, European Commission – Joint Research Centre.

Holscher, M., Ignell, D., Lewis, M. and Stiroh, K. (2022), “Climate Change and the Role of Regulatory Capital: A Stylized Framework for Policy Assessment”, Finance and Economics Discussion Series, No 068; Board of Governors of the Federal Reserve System, October.

Huizinga, J., De Moel, H. and Szewczyk, W. (2017), “Global flood dept-damage functions: Methodology and the database with guidelines, JRC Technical Reports.

Hsiang, S.M. and Jina, A.S. (2014), “The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence From 6,700 Cyclones”, NBER Working Paper Series, No 20352, National Bureau of Economic Research, July.

Intergovernmental Panel on Climate Change (2022a), “Summary for Policymakers”, in IPCC (ed.) Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, pp. 3-33.

Intergovernmental Panel on Climate Change (ed.) (2022b), Climate Change 2022: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Intergovernmental Panel on Climate Change (2023), Climate Change 2023: Synthesis Report. Summary for Policymakers.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2022), “The methodological assessment report on the diverse values and valuation of nature: summary for policymakers”.

International Energy Agency (2022), "**The Role of Critical Minerals in Clean Energy**", World Energy Outlook Special Report.

Jourde, T. and Moreau, Q. (2022), "Systemic Climate Risk", December.

Jurča, P., Klacso, J., Tereanu, E., Forletta, M. and Gross, M. (2020), "The Effectiveness of Borrower-Based Macroprudential Measures: A Quantitative Analysis for Slovakia", IMF Working Papers, No 134, International Monetary Fund, July.

Kauko, K., Manninen, O., Saada, A. and Tiililä, N. (2021), "Increased flood risks caused by climate change will also affect banks", Bank of Finland Bulletin, Suomen Pankki – Finlands Bank, January.

Kölbel, J.F., Heeb, F., Paetzold, F. and Busch, T. (2020), "Can Sustainable Investing Save the World? Reviewing the Mechanisms of Investor Impact", Organization & Environment, Vol. 33, Issue 4, pp. 554-574.

Kribich et al. (2022), "The challenge of unprecedented floods and droughts in risk management", Nature, Vol. 608, pp. 80-86.

Krupnick, A. and Parry, I.W.H. (2012), "What is the Best Policy Instrument for Reducing CO2 Emissions?", in Parry, I.W.H., de Mooij, R. and Keen, M. (eds.) Fiscal Policy to Mitigate Climate Change. A Guide for Policymakers, International Monetary Fund, pp. 1-25.

La Notte, A., Grammatikopoulou, I., Zurbaran Nucci, M., Marques, A., Ferrini, S., Cerilli, S. and Tamborra, M. (2022a), "**LInking accounts for ecosystem Services and Benefits to the Economy THrough bridging (LISBETH) Part II**", September.

La Notte, A., Vallecillo, S., Grammatikopoulou, I., Polce, C., Rega, C., Zulian, G., Kakoulaki, G., Grizzetti, B., Ferrini, S., Zurbaran-Nucci, M., Garcia Bendito, E., Vysna, V., Paracchini, M.L. and Maes, J. (2022b), "**The Integrated system for Natural Capital Accounting (INCA) in Europe: twelve lessons learned from empirical ecosystem service accounting**", One Ecosystem, Vol. 7.

Lamas Rodríguez, M., Garcia Lorenzo, M.L., Medina Magro, M. and Perez Quiros, G. (2023), "Impact of climate risk materialization and ecological deterioration on house prices in Mar Menor, Spain", Scientific Reports, Vol. 13, Issue 1.

Lang, J.H. and Forletta, M. (2020), "Cyclical systemic risk and downside risks to bank profitability", Working Paper Series, No 2405, ECB, Frankfurt am Main, May.

Luo, L., Tang, Q., Fan, H. and Ayers, J. (2023), "Corporate carbon assurance and the quality of carbon disclosure", Accounting & Finance, Vol. 63, Issue 1, pp. 657-690.

Marmolejo-Duarte, C. and Chen, A. (2022), "The effect of energy performance ratings over residential prices or how an insufficient control of architectural-quality may render spurious conclusions", Cities, Vol. 126.

Natural Capital Finance Alliance and UN Environment World Conservation Monitoring Centre (2018), “Exploring Natural Capital Opportunities, Risks and Exposure: A practical guide for financial institutions”, December.

Network for Greening the Financial System (2020a), “The Macroeconomic and Financial Stability Impacts of Climate Change: Research Priorities”, June.

Network for Greening the Financial System (2020b), “NGFS Climate Scenarios for central banks and supervisors - First vintage”, June.

Network for Greening the Financial System (2021), “NGFS Climate Scenarios for central banks and supervisors - Second vintage”, June.

Network for Greening the Financial System (2022a), “Statement on Nature-related Financial Risks”, March.

Network for Greening the Financial System (2022b), “NGFS Climate Scenarios for central banks and supervisors - Third vintage”, September.

Network for Greening the Financial System (2023a), “Nature-related Financial Risks: a Conceptual Framework to guide Action by Central Banks and Supervisors”, September.

Network for Greening the Financial System (2023b), “Conceptual note on short-term climate scenarios”, October.

Network for Greening the Financial System (2023c), “Compound Risks: Implications for Physical Climate Scenario Analysis”, November.

Network for Greening the Financial System (2023d), “NGFS Climate Scenarios for central banks and supervisors - Fourth vintage”, November.

Network for Greening the Financial System and Financial Stability Board (2022), “Climate Scenario Analysis by Jurisdictions: Initial findings and lessons”, November.

Ojea-Ferreiro, J., Panzica, R. and Papadopoulos, G., (forthcoming), “Climate stress test of the global supply chain network: the case of river floods”, JRC Working Papers in Economics and Finance, European Commission – Joint Research Centre.

Oliveri, E. and Santoro, M. (2000), “Estimation of urban structural flood damages: The case study of Palermo”, Urban Water, Vol. 2, Issue 3, pp. 223-234.

Papadopoulos, G. (2022), “Discrepancies in corporate GHG emissions data and their impact on firm performance assessment”, JRC Working Papers in Economics and Finance, No 12, European Commission – Joint Research Centre, October.

Papadopoulos, G. (2023), “External assurance of carbon disclosures indicates possible underestimates in reported European corporate emissions data”, JRC Working Papers in Economics and Finance, No 09, European Commission – Joint Research Centre, August.

Perez-Quiros, G., Rodriguez, M.L., Lorenzo, M.D.L.L.G. and Magro, M.M. (2022), “When Macro Critical Climate Risk Comes True. Environmental Destruction and House Prices in Mar Menor, Spain”, December.

Pörtner, H-O. et al. (2021), “**Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change**”, June.

Schipper, A.M., Hilbers, J.P., Meijer, J.R., Antão, L.H., Benítez-López, A., de Jonge, M.M.J., Leemans, L.H., Scheper, E., Alkemade, R., Doelman, J.C., Mylius, S., Stehfest, E., van Vuuren, D.P., van Zeist, W.J. and Huijbregts, M.A.J. (2020), “**Projecting terrestrial biodiversity intactness with GLOBIO 4**” Global Change Biology, Vol. 26, Issue 2, pp. 760-771.

Simoens, M., Emambakhsh, T., Bartsch, F., Spaggiari, M., Busies, I., Grill, M. and Tamburrini, F. (2023), “Climate Systemic Risk Buffer: a methodology and application”, forthcoming.

Steinhausen, M., Paprotny, D., Dottori, F., Sairam, N., Mentaschi, L., Alfieri, L., Lüdtke, S., Kreibich, H. and Schröter, K. (2022), “Drivers of future fluvial flood risk change for residential buildings in Europe”, Global Environmental Change, Vol. 76.

Stern, N. (2021), “Climate protection: state of play, division of labour, steps forward”, keynote lecture, Oesterreichische Nationalbank, 7 October.

Stiroh, K. (2022), “Climate Change and Double Materiality in a Micro- and Macroprudential Context”, Finance and Economics Discussion Series, No 066, Board of Governors of the Federal Reserve System, May.

Svartzman, R., Espagne, E., Gauthey, J., Hadji-Lazaro, P., Salin, M., Allen, T., Berger, J., Calas, J., Godin, A. and Vallier, A. (2021), “A ‘Silent Spring’ for the Financial System? Exploring Biodiversity-Related Financial Risks in France”, Working Paper Series, No 826, Banque de France, August.

United Nations et al. (2021), “**System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA)**”, white cover publication, pre-edited text subject to official editing.

Vallecillo, S., Van Loo, M., La Notte, A., Zurbaran Nucci, M., Zulian, G., Polce, C., Grammatikopoulou, I., Maes, J., Tamborra, M., Garcia Bendito, E., Grizzetti, B., Rega, C., Kakoulaki, G., Danckaert, T., Buchhorn, M., De Roo, B., Broeks S. and Smets, B. (2022), “**Ecosystem services accounts: maps for 7 ecosystem services produced in KIP INCA 2018 updates**”, European Commission – Joint Research Centre.

Van Toor, J., Piljic, D., Schellekens, G., Van Oorschot, M. and Kok, M. (2020), “**Indebted to nature – Exploring biodiversity risks for the Dutch financial sector**”, De Nederlandsche Bank, June.

Vasicek, O. (2002), “The Distribution of Loan Portfolio Value”, RISK, Vol. 15, No 12, pp. 160-162.

World Bank and Bank Negara Malaysia (2022), “**An Exploration of Nature-Related Financial Risks in Malaysia**”, March.

Imprint and acknowledgements

This report was prepared jointly by the ESRB Advisory Technical Committee and Eurosystem Financial Stability Committee.

Project team leads

Jean Boissinot (Banque de France – BdF) Paul Hiebert (European Central Bank – ECB)

Workstream leads

Surveillance framework	Stephan Fahr (ECB) and Thomas Allen (BdF)
Policy considerations	Michael Grill, Fabio Tamburrini (ECB) and Ludivine Berret (BdF)
Nature-related risks	Laura Parisi (ECB) and Julja Prodani (De Nederlandsche Bank)

Secretary

Dejan Krusec and Pablo Serrano Ascandoni (ECB)

Core drafting team

Chapter 2 – Surveillance framework

Tamanna Adhikari
Maria Alessia Aiello
Lucia Alessi
Thomas Allen
Elsa Allmann
Stefano Battiston
Florian Bartsch
Mario Bellia
Calogero Brancatelli
James Carroll
Paul Champey
Ricardo Crisóstomo
Francesca Di Girolamo
Justin Dijk
Tina Emambakhsh
Stephan Fahr
Serena Fatica
Christian Gross
Margherita Giuzio
Alexander Harris
Philipp Haenle
Julika Herzberg
Csilla Königswieser
Derek Lambert
Georgia Lialiouti
Ricardo Marques
Malgorzata Osiewicz
Irene Pablos Nuevo
Georgios Papadopoulos
Andrea Pagano
Marco Petracco Giudici
Riccardo Pizzeghello
Roberto Panzica
Paul Reiche
Nuno Ribeiro
Caterina Rho
Cornelius Schmidt
Vanessa Schoeller
Richard Senner
Mathieu Simoens
Iskra Sokolovska
Eveline Turturescu
Josep-Maria Vendrell
Andrea Vismara
Oriane Wegner
Lu Zhang

Chapter 3 – Policy considerations

Daniel Abreu
Claudio Bassi
Ludivine Berret
Florian Bartsch
Iulia Busies
Marianna Caccavaio
Tina Emambakhsh
Jari Friebel
Michael Grill
Angeliki Gkiza
Margherita Giuzio
Widmer Gregori
Anca Hotaranu
Katrin Johanson
Samu Kärkkäinen
George Kaoudis
Deborah Leboullanger
Maximilan Ludwig
Ludovico Ridi
Mathieu Simoens
Chiara Sandon
Martina Spaggiari
Siegfried Steinlein
Stephanie Stolz
Wolfgang Strohbach
Fabio Tamburrini
Arien Van't Hof
Roman Vasil
Josep-Maria Vendrell-Simon
Marton Zsigó

Chapter 4 – Nature-related risks

Sara Balitzky
Andreas Barkman
Annette Becker
Simone Boldrini
Andrej Ceglar
Ricardo Crisóstomo
Francesca Di Girolamo
Gorm Dige
Ivan Faiella
Marie Gabet
Ioanna Grammatikopoulou
Andrea Hagyo
Dominik Hirschbuehl
Paolo Krischak
Alessandra La Notte
Maximilian Ludwig
Aikaterini Paisou
Marco Petracco
Julja Prodani
Caterina Rho
Amalia Stamate
Romain Svartzman
Luminita Tatarici

Team members

Daniel Abreu
Lucia Alessi
Maria Alessia Aiello
Thomas Allen
Elsa Allman
Arno Altoja
Tuulia Asplund
Maria Luisa Babo Rodrigues
Sara Balitzky
Andreas Barkman
Florian Bartsch
Ivana Baranović
Claudio Bassi
Annette Becker
Mario Bellia
Ludivine Berret
Jean Boissinot
Simone Boldrini
Iulia Busies
Marianna Caccavaio
Simone Caldera
Jari Friebel
Marie Gabet
Margherita Giuzio
Angeliki Gkiza
Ioanna Grammatikopoulou
Wildmer Gregori
Michael Grill
Christian Gross
Philipp Haenle
Andrea Hagyo
Alexander Harris
Dominik Hirschbuehl
Anca Hotaranu
Katrin Johanson
George Kaoudis
Karlo Kauko
Samu Kärkkäinen
Paolo Krischak
Csilla Königswieser
Alessandra La Notte
Georgia Lialiouti
Matthias Sydow
Irene Pablos
Aikaterini Paisiou
Roberto Panzica
Georgios Papadopoulos
Laura Parisi
Raffaele Passaro
Marco Petracco
Wolfgang Pointner
Julja Prodani
Benno Schumacher
Wolfgang Strohbach
Stephanie Stolz
Chiara Sandon
Iskra Sokolovska
Amalia Stamate
Romain Svartzman
Paul Reiche
Ludovico Ridi
Nuno Ribeiro
Caterina Rho

James Caroll
Andrej Ceglar
Paul Champey
Jelena Ćirjaković
Kim Creminger
Ricardo Crisóstomo
Mattias Danielsson
Gorm Dige
Tina Emambakhsh
Stephan Fahr
Ivan Faiella
Serena Fatica
Federico Lubello
Maximilan Ludwig
Déborah Leboullenger
Ricardo Marques
Enric Martorell Toledano
Luca Mingarelli
Martin Santa
Cornelius Schmidt
Richard Senner
Pablo Serrano Ascandoni
Martina Spaggiari
Siegfried Steinlein
Luminita Tatarici
Fabio Tamburrini
Emiliano Tornese
Eveline Turturescu
Panagiotis Tzortsias
Roman Vasil
Josep Vendrell Simon
Oriane Wegner
Christiane Westhoff
Katrin Weissenberg
Marton Zsigo
Lu Zhang

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website **www.esrb.europa.eu**

For specific terminology please refer to the **ESRB glossary** (available in English only).

PDF ISBN 978-92-9472-353-6, doi:10.2849/846786, DT-02-23-313-EN-N