GENERALI INSURANCE ASSET MANAGEMENT

CORE MATTERS

Climate change: a challenge for financial stability?

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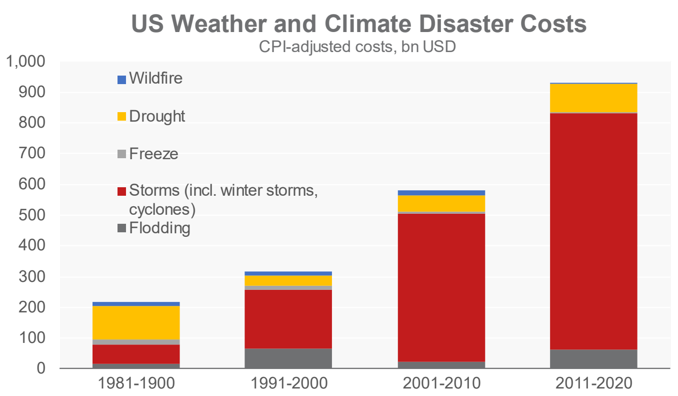
March 6, 2023

Our Core Matters series provides thematic research on macro, investment, and insurance topics

- Climate change is rising quickly in importance as a “new” risk factor to financial stability. It may negatively impact borrowers’ ability to service debt physically (via asset damages) and/or economically (via curbing production, sales, and profitability or via the devaluation of pledged collateral).
- Studies suggest that financial stability risks for the European financial system are currently manageable. However, about 30% of the euro area banking system’s credit exposures accrue from firms with high or increasing climate-related risk.
- Risks are unequally distributed across locations and sectors. This is true within Europe but even more on a global scale. EM countries are most vulnerable to environmental risk. They are facing the most severe impact and may lose a relevant part of their fiscal flexibility while mastering the green transition and containing climate-related risks.



Source: NOAA National Centers for Environmental Information, GIAM calculations

- Climate risks and costs are on a steep upward slope (chart). Thus, the true challenge for supervisors as well as financial intermediaries is to prepare for a future, still surrounded by huge uncertainties about the materialisation of the climate scenario. The ECB stress tests provide “state of the art” simulations based on three such scenarios. They suggest that financial losses would be lowest in an orderly transition to a low-carbon economy. By contrast, “doing nothing” would result in massive long-term GDP loss and financial damages. Climate change will not only impact firms, but also sovereign country risk via lower growth, higher inflation, and potential rating downgrades.
- Regulation is currently overhauling the Basel framework and the EU macroprudential framework. Especially climate specific capital buffers will punish brown sector exposure so that investors will need to carefully scrutinise firms on their ability to decarbonize their activities. This will need to go hand in hand with more climate modelling expertise and a more in-depth analysis of individual (bank) exposures. Brown sectors and financial institutions with a relatively high brown exposure will likely underperform.

CONTENT

1. Introduction

Climate change is quickly rising in importance as a "new" risk factor to financial stability. A quick look at the Global Risk Report 2023 shows the predominance of climate. The basic translation mechanism to financial risk is rather straight-forward. The financial sector mirrors the production, investment, demand, and wealth structure of the economy. Climate-related damages to this structure will inevitably be felt in financial institutions and markets. To assess and monitor risks, large amounts of data is required to map out "who is exposed to what factor". Moreover, risks may be correlated, amplified, generate feedback loops, show non-linearities, induce "fire sales" etc., thus possibly resulting in systemic threats. Consequently, central banks and regional regulators like the European Systemic Risk Board (ESRB) or the Bank of International Settlements (BIS) have put climate risk on top of their agendas. Central banks around the world coordinate research within the Central Banks and Supervisors Network for Greening the Financial System (NGFS). The BIS has also taken stock of its members' initiatives.

Starting with "what are the risk factors", we introduce the typical distinction of physical and transition risks and focus on how financial agents (topics on banks, insurers) are currently affected (chapter 2). Geographically, EMs are the most exposed regions (chapter 3). Climate risks will become increasingly tangible in the future, depending on today's policy action. To capture how these risks could evolve, we introduce climate scenarios and model predictions including stress tests (chapter 4). Central banks are trying to help and reduce the risks, and for this are adapting macroprudential frameworks (chapter 5).

2. Climate-related risk factors and risk quantification for banks and insurers

Climate risk drivers are typically classified into **physical** and **transition** risks (BIS). Global warming translates into an increasing strength and frequency of extreme (physical) weather events, which often create permanent damages. Physical risks are often further subcategorised into acute (heatwaves, floods, etc) and chronic hazards (rising sea levels, etc). Transition risks result from the "transitioning" of an economy from a fossil fuel-based to a low-carbon economy. The main impact arises from decarbonisation policies but may also rely on innovation and changes in the affordability of existing technologies.

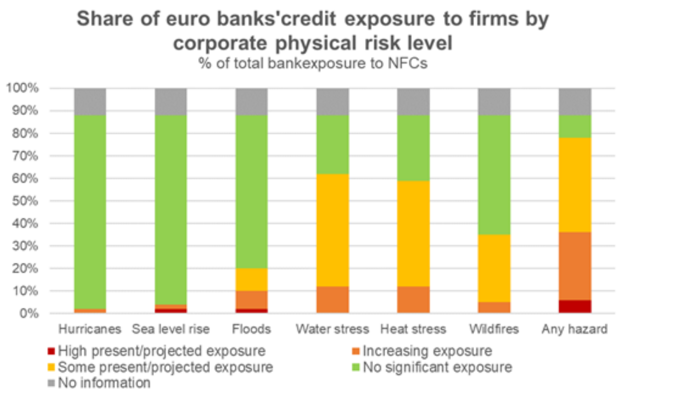
Climate-related exposure-risk framework

		Exposure dimension	Risk dimension
Institution-specific	Non-financial	**Transition** Emissions (actual and forward-looking) **Physical** Climate-related hazards (floods, wildfires, heatwaves, etc)	**Transition** Impact on profits and costs, risk perception, tech. obsolescence) **Physical** Asset damage, insurance costs, production disruption
Institution-specific	Financial	**To non-financial sectors** • credit instruments (loans, debt, equity) • contingent liabilities (insurance, derivatives)	**Vulnerabilities of counterparties:** indebtedness, leverage, provision **Climate-rel. impact on credit risk:** PD, LGD, market risk (valuation)
System-wide		**Climate:** interdependent hazards **NFCs**: In-/output interdependencies **Fin. Institutions**: overlap. exposure	**Financial Interconnectedness, clustered risks** Dynamic risk amplification and propagation (joint defaults, fire sales, contagion)

Source: adapted from ECB/ESRB: The macroprudential challenge of climate change, July 2022, GIAM

Physical and transition risk increase the credit risk via the borrower's ability to service and repay debt, or by the devaluation of pledged collateral. Physical risk mainly impacts banks and financial intermediaries' risk via asset damages of their counterparties. Transition risks may affect corporates through changes in production, investments, costs, sales, and profitability within the transition period. Thus, climate exposure varies with **geographic** location of counterparties, national climate policies and – of course – the credit portfolios. An effective risk management framework for banks, financial intermediaries and supervisors should **map** climate-related exposures and risk concentration and **quantify** them (see BIS for existing methodologies). Given their distinct features, physical and transition risks are often assessed separately - an approach we also follow.

Euro area banking sector exposures to physical risks: Assessing financial system exposures to physical risk requires granular geo-spatial information to the physical risks of counterparties (ESRB 2021). In Europe, the main climate-related physical risks are floods, water stress, heat stress and wildfires. This appraisal is based on the analysis of the "Four Twenty Seven" data collection (now Moody's), covering about 1.5 million firms in Europe. The database proxies the location of firms' headquarters as being relevant for physical damage exposure. The geographical distribution of physical risk hotspots differs by risk factor. Flood risks, although a relevant factor in many countries, are more strongly concentrated in central and northern Europe. Heat stress, water stress and wildfires predominantly affect southern Europe



Source: adapted from ECB/ESRB: Climate-related risk and financial stability, July 2021, GIAM

To derive the banking sector risk exposure, the above results are combined with AnaCredit. This shows that around 30% of euro area banking system credit exposures are to firms with high or increasing risk, owing at least to one physical risk factor. Banking system exposures to any physical risk drivers amount to up to 80% (right column in graph above).

According to ESBR (2021), risks are concentrated among few banks. "More than 70% of the banking system credit exposures to the identified high-risk firms are held by 25 banks" (in a sample of 357 banks). Fortunately, these banks are generally large, well-diversified, and have additional capital buffers given their status as global or other systemically important banks. "As a result, their loan exposure […] is generally lower than 7% of their total assets, with seven banks having exposures of more than 10%."

Banking sector exposures to transition risks: The transition risk measurement typically concentrates on the exposure to CO2 emissions, as they are expected to become increasingly costly. One practice among banks is to analyse to what extent certain sectors could be affected (climate policy-relevant sectors, CPRS). Those high emission sectors include **oil and gas, utilities, transportation, parts of manufacturing, metals and mining, and construction**. A more granular approach tries to calculate the carbon footprint of banks' assets (i.e., the financed emissions). Of course, counterparties' emissions disclosures are a limiting factor.

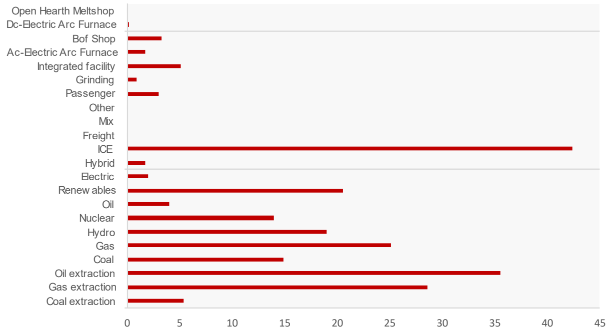
The ESRB (2021) report finds that bank loan exposures to CPRS in the euro area amount to around 50% of total loans to the non-financial sector, very much concentrated in the housing (36%) and energy-intensive sectors (8%). However, it turns out that the weighted emissions intensity[1] of the loan portfolio is around one-third lower than the emissions intensity of (1.5m considered) firms in the euro area. Thus, the **loan portfolio is "greener" than the economy**. The top 15 emissions-intensive NACE 2 sectors in the EU statistical classification system (mainly from manufacturing, electricity, transportation, and construction) are responsible for around two-thirds of bank loan-weighted emissions intensity but account only for 11% of the euro area non-financial companies (=NFC) loan portfolio. Nevertheless, specific vulnerabilities remain due to the variability among and within sectors. One is the highly emitting utility sector while the absolute level of loans to the sector is limited.

Insurance sector physical and transitional risks: Non-life insurers are most heavily exposed to **flood** risk in Europe. In France, Germany, and the United Kingdom, this (average) risk represents "72% of total exposures across all regions. Moreover, the natural catastrophe risk charge for the flood risk […] accounts for 57% of the total natural catastrophe risk charge […]." Climate change implies that estimates over past losses are not reliable to predict future losses. The latter implicate a rising protection gap. "In the past, only 35% of the total losses caused by extreme weather and climate-related events across Europe were insured." (ESBR 2021) At the macro level, the insurance quota decisively influences the recovery process.

Insurers transition risks are mostly sourced in their equity and corporate bond holdings of firms in climate-relevant sectors. Data show relatively substantial holdings in the power sector, oil and gas as well as vehicle production. In most cases, the risks appear manageable, as insurers hold relatively well-

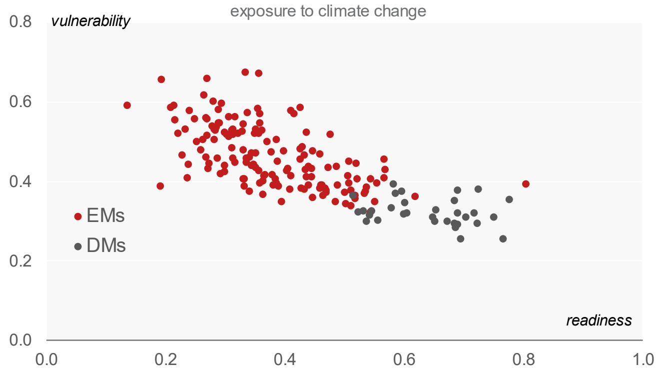
[1] Defined as total emissions, i.e. CO2 of scope 1 and scope 2 emissions of the Green-house-gas (=GHG) protocol, over revenue.

Value of investments by insurer in key climate policy-relevant sectors
Q4 2019, euro bn



Source: adapted from ECB/ESRB: Climate-related risk and financial stability, July 2021, GIAM

EMs: more vulnerable
exposure to climate change



Source: ND, GIAM

diversified portfolios (and run divestment plans for high-carbon assets). However, additional risks remain due to their engagement in investment funds (only about 17% of total investments are (partly) labelled ESG, thus potentially exposed to high emissions, ESBR 2021).

3. Global distribution of environmental risks

EM countries are most vulnerable to environmental risk. Climate risk distribution is uneven across the globe as both physical and transition risks will differ in intensity and manifestation. Accordingly, the potential economic damage will vary greatly. Emerging countries, by their geography, should be the most affected and not just because they have large surfaces and host most of the world population. Several studies show EM should also see the most extreme events, including the strongest temperature increase and sea level rise.

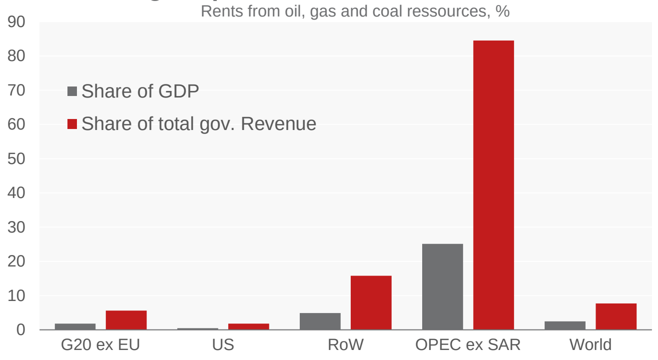
The climate change outlook and its consequences are uncertain, but history suggests that EMs and the poorest countries stand in the weakest position. The Global Climate risk index shows that since 1999 the top ten affected countries are all EMs. Likewise, the 20 most damaging natural disasters over the past 20 years have been all in EMs.

EM countries with the largest climate risk exposure are also the countries with the **lowest ability to cope**, both in terms of prevention and recovery. Their economies tend to be less diversified and reliant on sectors vulnerable to physical risk (agricultural, tourism) and transition risk (such as fossil fuel extraction), with limited financial capacity. This is confirmed by the Notre Dame (ND) Gain indices which capture a country's overall susceptibility to climate-related disruptions and capacity to deal with the consequences of climate change.

The resilience has been improving since the 2000s, but heterogeneity across countries is stark. Canada, Australia, some parts of South America, and Asia have improved their situation, while Sub-Saharan Africa has remained relatively unchanged over almost 20 years.

Transition risk constitutes a significant vulnerability for EMs. where fossil fuels account for nearly 5% of GDP, against 1.8% in the G20, and 15.8% of total government revenue. The poorest countries will face a double whammy: not only they face from the largest climate risks but they may also lose a relevant part of their fiscal flexibility as they initiate the transition and address these risks.

High exposure for EM to transition risks
Rents from oil, gas and coal ressources, %



Source: OECD, World Bank, UN ENvironment (2018), GIAM

4. Climate scenarios and their impact on physical and transition risks

In line with systemic risk analysis, we can distinguish between shocks to the financial systems – difficult to predict, impossible to time – and vulnerabilities. Vulnerabilities build over time and can amplify the impact of shocks. Research on the systemic impact of climate changes is relatively new but we can present some quantitative results already:

- Starting with **physical** risk, in a broad analysis on heat stress in the US Acharya et al. show that this risk is to some extent priced: they compute the relationship between asset prices/returns and various measures of exposure to heat stress, derived by locational data and probabilistic estimates of temperature change and rainfall. For S&P companies, one standard deviation to heat stress exposure (based on meteorological information and the location of production plants) translates into a 40bps spread for HY bonds and 45 bps premium on expected stock returns. Importantly, these results start showing up in the data only after 2013 and may be a lower bound for the cost estimates given the increase in intensity of the phenomena and the financial market awareness.

- Regarding **transition** risk, which can quickly result in stranded assets (like coal mines or oil wells), recent research by Ochoa et al., shows that the surprise decision, in December 2019, by the German parliament to set the price of CO2 m to €25/ton, instead of the initially planned €10, caused a significant impact on equity prices. A strategy long low-CO2 intensity firms and short high intensity firms would have yielded a 1.3% positive return on the day of the announcement.

However, deriving the implications for the whole financial sector requires a much more elaborate framework, with demanding data requirements and the need to account for wide uncertainty. This is typically accomplished by model suites, starting from (very long-term) climate scenarios which are then used to calibrate macro models (the National Institute General Economic Model – NiGEM – plays an important part here) which in turn are processed further into financial risk parameters (like default probabilities). Modelling location-specific climate evolution will provide a gauge of the impact of physical risk on a bank's loan portfolio and non-life insurers exposure. The ECB stress tests (see chapter 4.2.) combine all these features (and more, e.g. the preparedness of financial agents), and is seen as "state of the art".

4.1 Climate scenarios

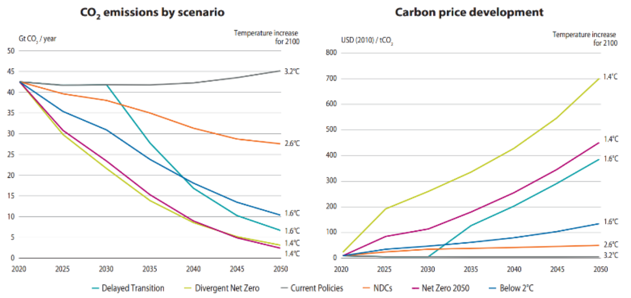
The multi-decade climate scenarios describe the evolution of temperature and other environmental variables as a function of the stock of CO2 emission. The cap on the latter reflects the ambition to limit global warming. There are several sources of climate scenarios, such as those of the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA); we focus here on the NGFS. It explores a set of six scenarios (see graph below) which are grouped into:

– **Orderly scenarios**, assuming climate policies are introduced early and become gradually more stringent. Both physical and transition risks are relatively subdued. The scenario "Net Zero 2050" limits global warming to 1.5°C. The "Below 2°C" scenario sees a gradual increase in the stringency of climate policies.

– **Disorderly scenarios** explore higher transition risks due to policies being delayed or divergent across countries and sectors. The "Divergent Net Zero" scenario reaches net zero around 2050 but with higher costs due to such divergence. The "Delayed Transition" scenario assumes annual emissions do not decrease until 2030 but then strong policies are needed/assumed to limit warming to below 2°C.

– **Hot house** world scenarios assume that selected climate policies are implemented in some jurisdictions, but globally efforts are insufficient to halt significant global warming. The "Current Policies" scenario assumes that only currently implemented policies are preserved, leading to a rise of average global temperature beyond 3°C while the "Nationally Determined Contributions (NDCs)" scenario includes all pledged targets even if not yet implemented. This is again insufficient to reach the Paris Agreement targets.

CO_2 Emissions and Carbon Price Development

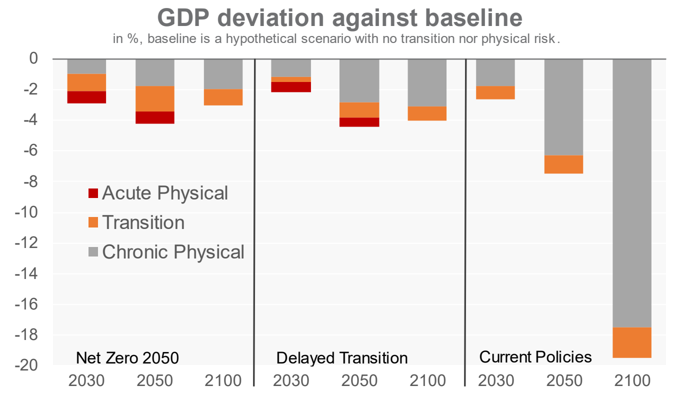


Source: IASA NGFS Climate Scenarios Database, REMIND model, NGFS Scenarios 2022, GIAM.

The graph below shows the long-term GDP impact of the three scenarios groups, together with its contributors. Without additional measures, the hot house "Current policies scenario" leads to a massive damage to GDP of up to 20 % compared to baseline by 2100[2] (the baseline scenario is a hypothetical scenario with no transition nor physical risk). Overall, orderly scenarios have less negative impact than

[2] This is the result of irreversible business disruptions and property damage. Labour productivity, agriculture, ecosystems and sea levels are significantly affected.

disorderly ones; the maximum loss (up to 6%) always comes during the adaption period. Within this period, there is a trade-off between early and delayed actions. While short term losses are lower, transition and physical damages are exacerbated afterwards.



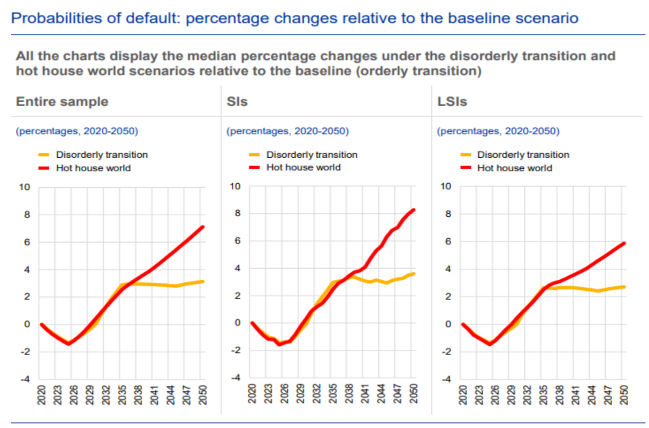
Source: IIASA NGFS Climate Scenarios Database, NiGEM model (REMIND inputs). , GIAM

4.2 The ECB stress Tests

The 2021 ECB economy wide climate stress test and the 2022 climate risk stress test are probably the most detailed simulation exercises to date, mostly focused on the impact on the euro area financial sector. They use as macro assumptions all the components described above. Especially, the exercise incorporates 1/ the projections for the main macro and financial variables obtained in the three macro scenarios (orderly, disorderly and hot house) 2/ location-based information on exposure to climate hazards (like drought and floods) and 3/ an assessment of which firms (and therefore loans) are more exposed to transition risk. This involves information on the carbon footprint of each sector (and ideally of individual firms) and the potential impact of decarbonisation on the balance sheet and the probability of default. Then the projections of the macro/financial variables are combined with the estimates of natural hazard risks, the cost of the assumed policy measure, and the impact on decarbonisation on firms' profitability. This allows to project probability of defaults, and in turn, a wide array of financial indicators, from non-performing loans to the strength of banks' capital buffers to credit spreads.

The estimated probability of default (=PD) and loss given default (=LGD) (see ESRB 2022) play an important role. Transition risks are affecting corporate profitability and may result in "stranded" or depreciated assets, reducing the available collateral for corporate loans. The materialisation of physical risk includes the destruction of physical capital, production and supply chain disruptions and higher insurance costs. In each climate scenario, the total losses of banks are derived by adding up corporate loan-specific expected losses, calculated by applying the loan-specific PD and LGD.

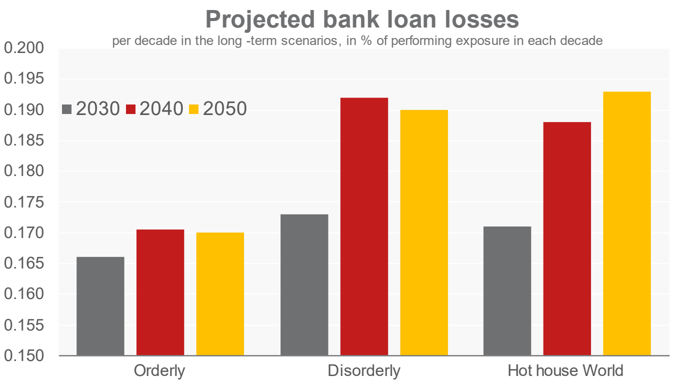
The charts below (taken from the 2021 ECB stress test) show the results. They specify the evolution of the default probabilities of banks' loan book, based on their portfolio composition in the disorderly transition and hot house (current policies) scenarios, shown as the difference from an orderly transition. In other words, how much worse will the "disorderly" or "hot-house" world become as compared to an orderly transition. In addition, the results are split between the largest banks (significant institutions, SI) and smaller entities (LSI).



As the costs of a green transition are relatively large, "doing nothing" leading to either a delayed intervention or a hot house scenario, initially yields a smaller probability of default. However, these effects are reversed rather quickly. By 2050, failing to mitigate physical risk would lead to a 7% increase in the median loan portfolio's probability of default, with stronger effects in those institution with a bigger, systemic impact on the financial landscape. In the disorderly-transition scenario, the deviation of PDs peaks in 2035 at roughly 2% due to the assumption that firms would finance transition by issuing new debt. This financial burden on firms would translate into banks' portfolios.

Moreover, in its 2022 stress test the ECB goes beyond the PDs and specifies losses for each scenario. "An orderly transition would lead to lower loan losses by 2050 (i.e. in the long run) relative to the disorderly and hot house world scenarios, particularly for sectors with high carbon intensity, such as mining and minerals" (ECB 2022). Even short term (3-year) risks are significant: "Banks are vulnerable to an abrupt and large increase in transition risk shock in the short term […]" showing […] "an increase in cumulated impairments of around 73 basis points compared with the baseline over the scenario horizon."

Accordingly, the ESRB 2022 concludes: "A timely and orderly transition to zero net emissions in 2050 would markedly reduce the credit losses of banks compared with the "current policies scenario". While at the beginning of the transition period, banks suffer losses of less than 0.1% of the loan value (or 14% compared to the current policies scenario), these are more than compensated (+0.2% of loan value or 27% compared to current policies) by 2050. Insurers and investment funds benefit from the greening of the economy due to an improved value of their assets (esp. equities).



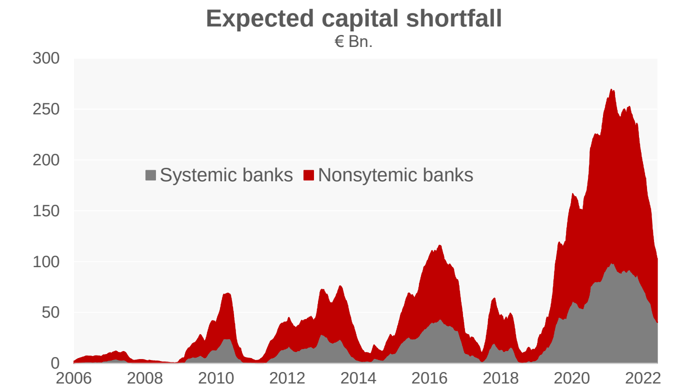
Source: ECB, 2022 climate risk stress test, July 2022, GIAM

4.3 NY Fed approach: application to EA banks

Exercises based on large micro datasets are very demanding and simpler models have been developed to analyse which banks may be financially more exposed to climate transition risk. Recently the New York Fed developed a tool to assess banks' resilience to transition risk, and more specifically to the emergence of stranded assets (like coal mines or oil wells). Using data on banks' equity prices and balance sheets it assesses the impact of a large decrease in the price of brown assets on the capitalisation of individual entities. The exercise involves the derivation of each bank's "climate beta", i.e., the sensitivity of the equity price to the value of a representative "brown" asset. A stylised balance sheet approach also assesses the capital shortfall induced by a drop in the price of the brown assets (Appendix 1 details the methodology).

We apply this methodology to a sample of around seventy euro area banks. A few interesting results emerge. Banks' equity sensitivity to transition risk – proxied by the beta to the brown assets' return – has increased, especially since the 2015 Paris Agreement. This reflects an increasingly negative correlation, signalling a higher market alertness to the exposure to stranded assets, similarly to what was found in the study on global banks that introduced this methodology. Climate betas vary over time, reflecting the swings in oil and other fossil fuels prices. The betas started edging up significantly after the 2015 drop in oil prices. The early-2020 pandemic-induced fall, while of comparable scale than that in between mid-2014 and early 2015 (around -55%), led to a much bigger rise of the climate beta, signalling a heightened market attention. After 2015 systemically important banks turned broadly more sensitive to swings in prices of fossil fuels, than smaller entities, which reflects their more global outreach and higher exposure to international energy producers. The surge in energy prices following the invasion of Ukraine has led to a decrease in betas, which however remain above the historical mean.

At the same time, according to this very simplified model, the theoretical capital shortfall induced by an extreme drop in the price of the brown asset (50%) increased to as much as 20% of equity in 2020. The following rebound in oil prices triggered a retrenchment, consistent with the evidence that demand for fossil fuels will not decline significantly in the short term. Systemically important banks account for roughly 40% of the total capital shortfall, despite accounting for just above 30% of market capitalisation.



Source:Refinitiv, GIAM

4.4 Sovereign risk and financial stability

Climate change will have significant impacts on sovereign risk via various transmission channels such as the fiscal impact of natural disasters, the cost of transition and adaption policies, and the long-term growth. The latest floods in Pakistan are a good example of how severe climate events can impact debt sustainability and accelerate the need for economic support from international institutions.

Beyond the direct impact on financial intermediaries like banks, climate events can affect monetary policy, leading to a further tightening as supply chains disruptions push up inflation. Moreover, a weaker banking system increases governments' implicit liabilities related to the need to backstop or bailout the credit industry to reduce systemic crisis.

Climate risk can also worsen a country's credit rating and increase borrowing cost, at a time when the fiscal space is reduced by climate events and transition policies require dedicated funding, threatening further debt sustainability. Credit rating agencies have started to highlight climate change as a potential risk to their credit rating, even if they have so far not triggered rating downgrades.

Estimations show that under different scenarios high-rated countries would be downgraded the most. In a (about) 2°C increase scenario, 55 sovereigns would face downgrades. EMs countries with weak ratings and vulnerabilities to climate changes will be downgraded but the move will be smaller given the weaker starting point. Yet the damage would be significant as they have very limited fiscal space due to extreme weather events impact. The consequence of a weaker rating is that economies with the greatest need for investment in adaptation and resilience are also those who will be struggling the most to finance it.

It is not clear that this is currently fully priced in by sovereign markets and investors. So far, demand at primary market for countries that are seen vulnerable and ill-prepared to the climate change prepared according to the Notre Dame index remains strong. There have been very few examples of investors not buying a country bond because of its climate change exposure. Several reasons can explain this lack of concerns. Firstly, ESG considerations have been gaining traction at the sovereign level but are less advanced than at the corporate level. A clear investable framework has not been set. Secondly, EM HY countries are the most exposed to the climate change and they tend to have a short duration. with the main EM HY indexes duration close to 5Y. Some sovereign bonds mature beyond 2060 and thus should integrate some sort of climate premium. That said, these bonds are usually issued by developed or IG-rated countries, less affected by climate risk. Thirdly, EM HY investors are more focussed on short-term idiosyncratic factors that can drive the short-term debt sustainability and the ability to pay in the very near future than on a long-term distant risk.

Still, some econometric studies bring evidence on the impact of climate risk on bond pricing, especially in low-income countries. Countries that are more vulnerable to climate change have higher bond yields and spreads. For instance, it is estimated that a 1 % increase in the Notre Dame vulnerability index leads to a 3% rise in long-term bond spreads of EM countries. Regarding advanced economies, the impact is not significant. More interestingly, climate resilience has a similarly significant impact on lowering the cost of borrowing. The climate impact is much greater in developing countries with weaker capacity to adapt. These results would suggest that countries with a large exposure to climate risk, mainly EM HY, will see a higher cost of funding, possibly leading to a vicious circle where the exposure to climate risk raises the debt financing and limit the space for climate resilience.

One solution that is emerging is the issuance of natural **catastrophe bonds (CAT)** where bondholders are not repaid in full (or not at all) if a specific catastrophe event occurs. The insurance against natural disasters can be considered an adaptation policy. The sovereign CAT market is still small. Broadening the investor base to the public sector can help to improve the market pricing of climate change. Another solution is the inclusion of natural disaster clause in classic sovereign bond, like in the recent Barbados issuance where the contract includes provisions for payments to bondholders to be deferred for up to two years in the event of a pre-defined natural disaster. The climate risk is not fully transferred to the bondholders and their economic interest is protected. Thus, Fitch rated the bond in line with the sovereign default rating. The structure provides some support for weaker countries and gives them flexibility to improve their payment capacity.

5. Moving towards a green macroprudential approach

Institutions like the ECB oversee the above outlined (non-linear) risks to the financial system. Risk concentration could additionally exacerbate the effect on financial stability. These are key factors challenging the present regulatory framework.

5.1 Overhaul of Basel framework needed

The Basel supervisory framework was designed to deal with traditional financial stability risks and has continuously been adjusted to new challenges. It consists of three pillars (1/ risk coverage, 2/ management and 3/ market discipline, see Appendix 2) regarding the capital supervision (complemented by the supervision of liquidity and large exposers). The latest modifications following the great financial crisis (GFC) are still being implemented. Yet, the framework needs to be further adapted to climate change. Climate risks are basically forward-looking, characterised by uncertainty about how these risks will manifest. By contrast, parts of the Basel framework are backward-looking, as they rely on historical data to gauge the relationships between risk factors and exposures (including adverse economic conditions or unexpected events). Moreover, a lack of reliable data on climate-related financial risks is a constant additional hurdle.

In more detail, the Basel framework faces the following difficulties. The credit standards under Pillar 1 tend to underestimate the climate risk effect: Climate risks can either be assessed by the Standardised Approach (SA) that uses risk weights and predefined drivers from the regulator or the Internal Ratings-based Approach (IRB) in order to derive risk-weighted assets. But in the SA approach key risks and drivers do not yet incorporate climate risks and can only indirectly capture their features. The IRB approach was not designed to tackle the complexities of climate risks; interactions or interdependencies among input factors are not considered either. Current capital buffers are not big enough to capture climate-related financial risks. And even if the risk-weighted assets (RWAs) were adjusted, sectoral and geographical concentration risks would remain. Climate-related risks exhibit significant concentrations at the regional, sectoral, and firm levels that the current large exposures (LE) standard does not consider. Operational risks are based on historical data and do not cover losses related to strategic and reputational risks caused by climate-related events (e.g., increases in funding costs or decreases in profit due to changes in market sentiment or technological developments).

Lastly, regarding liquidity supervision the objective of the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR) is to promote the short- and medium-term resilience of banks' liquidity risk profiles; yet managing climate risk may require a longer-term approach.

The Basel Committee is working intensively on these issues. Regarding the transition to net zero emissions, the Chair of Banking Supervision outlined some regulatory guidelines. In June 2022 the BIS already came up with a set of 18 principles with Principles 1 to 12 providing banks with guidance on effective management of climate-related financial risks, while principles 13 to 18 provide guidance for prudential supervisors (see Appendix 3). Bottom line, the adjustment of the Basel framework has just started. It is already evident that there will be substantial additional capital requirements for banks. A recent study by Finance Watch estimates that the 60 largest global banks have around $1.35 trillion of credit exposures to fossil fuel assets. Applying a 150% (higher) risk weight under the current Pillar 1 alone would imply additional capital in the range $157.0 billion to $210.2 billion, equivalent on average to around three to five months of banks' 2021 net income.

5.2 The ECB's green macroprudential framework

The BIS approach to adjust the regulatory environment overlaps with the ECB's macroprudential framework regarding banks. The Financial Stability Board (FSB) laid down in a recent Financial Stability Review the integration of sustainability risks in the prudential framework for **insurers and investment funds**. Further work is ongoing to assess the role of insurance companies in mitigating the macroeconomic costs of climate related catastrophes and designing effective related policies. Moreover, initiatives by the European Commission on an EU green bond standard or the EU Ecolabel for Retail Financial Products are part of the wider macroprudential approach.

Macroprudential supervision and the quantification of capital buffer requirements will also be guided by stress test outcome. Overall, simulations by the ESRB 2020 suggest that the effects of an abrupt policy (delayed transition) response or an asymmetric technological innovation shock on the financial sector appear limited. The mark-to-market losses remain contained and below 1% in terms of Common Equity Tier 1 (CET1) for the insurance and banking sectors under both scenarios. The results are not directly comparable with the much larger ones derived with the very simple model described in Section 4.3, as the latter uses a completely different methodology and another type of shock. Also, the repercussions on the real economy as measured via lending to the non-financial private sector remain limited.

That said, the ECB is well aware of shortcomings underlying this still rather traditional stress test approach. There is limited supervisory reporting for the exposure of the financial institutions to carbon-intensity. Also, better tailored models would be needed. They should consider long-term scenarios with a substantial sector level of detail to capture the differing evolution of lending to greener and browner sectors more comprehensively. In addition, acute physical risks should be included more granularly, to better assess the costs of policy inaction.

Within the EU, macroprudential measures focus on the banking sector, firm disclosures, the non-bank financial sector (insurers, investment funds, investment firm, financial markets) and on financing the transition (see Appendix 4). It becomes clear that the move towards a proper macroprudential green framework is ongoing and consists of various and sometimes very specific measures. The highest business impact will likely result from higher risk weights to brown assets in the case of banks and insurers. Simulations suggest that investment funds are most vulnerable to market valuation shocks suggesting that concentration limiting measures will play a key role. Outstanding is a very wide consensus that climate-specific capital buffers will need to be introduced. ECB calculations suggest that the capital buffers for euro area banks amount currently to somewhat above 14% of RWA. That said, the ECB's latest macroprudential report (see Box 9) discusses a banking crisis triggered by non-climate related factors where transition comes on top or, even worse, a fire sale of high carbon-assets occurs.

Simulations suggest that the additional buffer would amount to 0.5% of RWA in the second case, compared to 0.4% in the first one. The volume of total RWA was € 8768 bn as of Q3/2022. However, banks with concentrated transition risks would have to put aside up to 4.5% of RWA. Hence, regulations will depend on the expected path of climate change.

6. Conclusions

Climate change has been rapidly acknowledged as a major source of systemic risk/stability for the financial sectors. An evolving understanding of the linkages between climate activity and data limitations make a precise estimation of the size and drivers of financial risks difficult. Addressing the extreme uncertainty, stress tests aim at gauging systemic risks emanating from climate change. The simulated impact on the financial sector reinforces the case for quick and determined action to fight temperature increase. EMs are particularly affected: most of them are heavily exposed to climate change and financing adaptation could become prohibitive if capital markets start pricing more aggressively in their bond valuation the dangers related to global heating.

Of course, the needed long-term models rely on very strong assumptions, implicitly assuming that the way economies work remains broadly the same all along the decades-long projection horizon. Moreover, the main tool used to model policy choices is the introduction of a carbon tax, which is not yet widely used in practice. The impact of alternative measures, such as the heavy investment in renewables and energy efficiency, for example by the recent U.S. Inflation Reduction Act, have yet to be fully integrated into the models. This could mitigate the trade-off between cutting emission and maintaining growth and inflation at acceptable levels.

What the stress tests have already highlighted, though, is the need to update and adapt the framework for financial regulation. Capital buffers will need to increase by at least 0.4% of RWA to include risk from climate change: the final increase, is hard to estimate given the uncertainty on the economic impact of climate change. Our simple model based on equity prices and balance sheet items show that transition risk can be indeed very costly for banks – up to 15% of equity in case of an extreme repricing of brown assets – with potentially large difference across institutions. This presents investors in financial institutions' equity and debt with another challenge related to gauging the resilience to climate events and policy actions. Better data on exposures and improvements in the modelling of climate polices are a clear priority to facilitate the investment process. All in all, brown sectors and financial institutions with a relatively high brown exposure will likely underperform. We suggested a very simple method but this must be complemented by a more in-depth analysis based on individual bank exposures. Within the brown sector investors will need to carefully scrutinise firms on their ability to decarbonize their activities.

Appendix

Appendix 1

The Climate risk (CRISK) model[1]

Step 1: the derivation of the climate beta, i.e., the sensitivity of a banks' equity returns to the price of a "brown asset". For each bank in the sample, we estimate the following CAPM regression:

$$r_{it} = \beta_{it}^{MKT} MF_t + \beta_{it}^{CLIMATE} CF_t + \varepsilon_{it}$$

Where r_{it} represents the daily stock return of the i-th bank, ε_{it} is the error term, MF_t is a market factor (the MSCI EMU index), CF_t is the daily return a climate factor (in this case the "brown asset" described below), while β_{it}^{MKT} and $\beta_{it}^{CLIMATE}$ are their associated bank-specific dynamic betas. The climate factor reflects the evolution of "brown" assets likely to become stranded following the transition away from fossil fuels. Based on the WWF stranded asset total return swap, the stranded asset portfolio consists of a long position in "brown" asset, 30% Energy selector ETF 70% in the VanEck Coal ETF and a short position in the S&P500 ETF Trust (proxy for renewables). In order to get the time variable betas, we derive the conditional variance and covariance across, banks' equity, the market index and the climate factor using a recently developed technique for high-frequency data (the DCC- GARCH)

Step 2: the computation of the impact on capital of a systemic climate change event. First we define the capital shortfall for bank *i* on day *t* (CS), as the difference between the capital the bank has to hold and its equity:

$$CS_{it} = kA_{it} - W_{it} = k(L_{it} + W_{it}) - W_{it}$$
$$= kL_{it} - (1-k)W_{it}$$

With *k* prudential capital share, A asset , L:liabilities and W market value of equity. CS>0 means a capital surplus.

The expected capital shortfall conditional to a climate stress event, defined as a h-days cumulative fall in the stranded asset returns exceeding a threshold C, is

$$CRISK_{it} = E_t[CS_{it} | CF_{t:t+h} > C]$$

$$=k(L_{it+h} | CF_{t:t+h} > C) - (1-k)(W_{it+h} | CF_{t:t+h} > C)$$

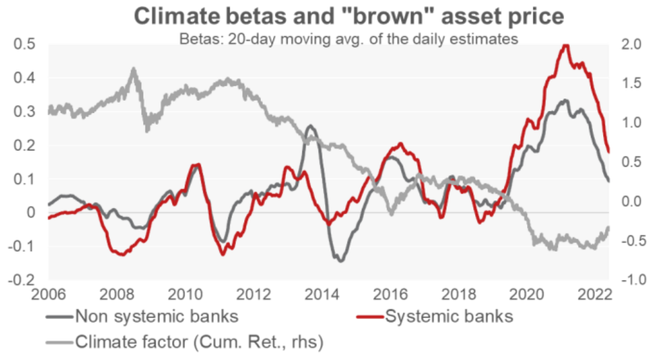
If the value of liabilities does not depend on the stress and is not renegotiable and defining the formula simplifies to:

$$CRISK_{it} = kL_{it} - (1-k)W_{it}(1 - LRMES_{it})$$

Step 3: Using the time varying climate beta, we get

$$CRISK_{it} = kL_{it} - (1-k)W_{it} exp\left(\beta_{it}^{CLIMATE} log(1-C)\right)$$

In order to compute the capital shortfall triggered by a climate risk event we first compute, for every bank and every day CRISK consistent with no shocks (C=0) and with a 50% drop in the value of the "Brown Assets", corresponding with the first percentile of distribution the six-month return of our "climate portfolio (i.e., returns were higher 99% of the time). Therefore, a bank's potential losses from climate risk depend not just on its exposure on stranded assets, but also size and leverage.



Source:Refinitiv, GIAM

[1] **The model was calculated with the help of Pierpaolo Coccia (Intern at Macro & Market Research)**

Appendix 2

Basel III supervision

green: areas with significant expected changes due to the incorporation of climate-related factors and risks

	Capital					Liquidity
	Pillar 1			Pillar 2	Pillar 3	
	Capital	*Risk coverage*	*Containing leverage*	*Risk management and supervision*	*Market discipline*	*Global liquidity standards and supervisory monitoring*
All banks	**Quality and level of capital** • **Raising minimum common equity** • **Capital conservation buffer** • **Countercyclical buffer** • **Capital loss absorption at the point of non-viability**	**Revisions to the standardised approaches** for calculating • **credit risk;** • **market risk;** • **credit valuation adjustment risk; and** • **operational risk** mean greater risk-sensitivity and comparability. **Constraints on using internal models** **Counterparty credit risk** **Securitisations** **Capital requirements for exposures to central counterparties (CCPs) and equity investments** A **revised output floor,** limits the regulatory capital benefits that a bank using internal models can derive relative to the standardised approaches	A non-risk based **leverage ratio** including off-balance sheet exposures	**Supplemental Pillar 2 requirements** address firm-wide governance and risk management, **Interest rate risk in the banking book (IRRBB)**	**Revised Pillar 3 disclosure requirements** Introduces a dashboard of banks' key prudential metrics.	**Liquidity Coverage Ratio (LCR)** Longer-term, structural **Net Stable Funding Ratio** (NSFR) **Principles for Sound Liquidity Risk Management and Supervision** **Supervisory monitoring**
SIBs	The Committee identifies global systemically important banks (G-SIBs) which must have higher loss absorbency capacity. The Committee also developed principles on the assessment methodology and the higher loss absorbency requirement for domestic systemically important banks (D-SIBs)					*Large exposures* Mitigate systemic risks arising from interlinkages across financial institutions and concentrated exposures

Source: Generali Investments, https://www.bis.org/bcbs/basel3/b3_bank_sup_reforms.pdf

Appendix 3

Basel Committee on Banking Supervision: Principles for the effective management and supervision of climate-related financial risks

Corporate governance	**Principle 1:** Banks should develop and implement a sound process for understanding and assessing the potential impacts of climate-related risk drivers on their businesses and on the environments in which they operate. Banks should consider material climate-related financial risks that could materialise over varioustime horizons and incorporate these risks into their overall business strategies and risk management frameworks.
	Principle 2: The board and senior management should clearly assign climate-related responsibilities to members and/or committees and exercise effective oversight of climate-related financial risks. Further, the board and senior management should identify responsibilities for climate-related risk management throughout the organisational structure.
	Principle 3: Banks should adopt appropriate policies, procedures and controls that are implemented across the entire organisation to ensure effective management of climate-related financial risks.
Internal control framework	**Principle 4:** Banks should incorporate climate-related financial risks into their internal control frameworks across the three lines of defence to ensure sound, comprehensive and effective identification, measurement and mitigation of material climate-related financial risks.
Capital and liquidity adequacy	**Principle 5:** Banks should identify and quantify climate-related financial risks and incorporate those assessed as material over relevant time horizons into their internal capital and liquidity adequacy assessment processes, including their stress testing programmes where appropriate.
Risk management process	**Principle 6**: Banks should identify, monitor and manage all climate-related financial risks that could materially impair their financial condition, including their capital resources and liquidity positions. Banks should ensure that their risk appetite and risk management frameworks consider all material climate-related financial risks to which they are exposed and establish aa reliable approach to identifying, measuring, monitoring and managing those risks.
Management monitoring and reporting	**Principle 7:** Risk data aggregation capabilities and internal risk reporting practices should account for climate-related financial risks. Banks should seek to ensure that their internal reporting systems are capable of monitoring material climate-related financial risks and producing timely information to ensure effective board and senior management decision-making.
Comprehensive management of credit risk	**Principle 8:** Banks should understand the impact of climate-related risk drivers on their credit risk profiles and ensure that credit risk management systems and processes consider material climate-related financial risks.
Comprehensive management of market, liquidity, operational and other risks	**Principle 9:** Banks should understand the impact of climate-related risk drivers on their market risk positions and ensure that market risk management systems and processes consider material climate-related financial risks. [
	Principle 10: Banks should understand the impact of climate-related risk drivers on their liquidity risk profiles and ensure that liquidity risk management systems and processes consider material climate-related financial risks
	Principle 11: Banks should understand the impact of climate-related risk drivers on their operational risk and ensure that risk management systems and processes consider material climate-related risks. Banks should also understand the impact of climate-related risk drivers on other risks9 and put in place adequate measures to account for these risks where material. This includes climate-related risk drivers that might lead to increasing strategic, reputational, and regulatory compliance risk, as well as liability costs associated with climate-sensitive investments and businesses.
Scenario analysis	**Principle 12:** Where appropriate, banks should make use of scenario analysis10 to assess the resilience of their business models and strategies to a range of plausible climate-related pathways and determine the impact of climate-related risk drivers on their overall risk profile. These analyses should consider physical and transition risks as drivers of credit, market, operational and liquidity risks over a range of relevant time horizons.
Prudential regulatory and supervisory requirements for banks	**Principle 13:** Supervisors should determine that banks' incorporation of material climate-related financial risks into their business strategies, corporate governance and internal control frameworks is sound and comprehensive.
	Principle 14: Supervisors should determine that banks can adequately identify, monitor and manage all material climate-related financial risks as part of their assessments of banks' risk appetite and risk management frameworks.
	Principle 15: Supervisors should determine the extent to which banks regularly identify and assess the impact of climate-related risk drivers on their risk profile and ensure that material climate-related financial risks are adequately considered in their management of credit, market, liquidity, operational, and other types of risk. Supervisors should determine that, where appropriate, banks apply climate scenario analysis.
Responsibilities, powers and functions of supervisors	**Principle 16:** In conducting supervisory assessments of banks' management of climate-related financial risks, supervisors should utilise an appropriate range of techniques and tools and adopt adequate follow-up measures in case of material misalignment with supervisory expectations.
	Principle 17: Supervisors should ensure that they have adequate resources and capacity to effectively assess banks' management of climate-related financial risks.
	Principle 18: Supervisors should consider using climate-related risk scenario analysis to identify relevant risk factors, size portfolio exposures, identify data gaps and inform the adequacy of risk management approaches. Supervisors may also consider the use of climate-related stress testing to evaluate a firm's financial position under severe but plausible scenarios.11 Where appropriate, supervisors should consider disclosing the findings of these exercises.

Source: https://www.bis.org/bcbs/publ/d532.pdf, GIAM

Appendix 4

EU macroprudential policies

	Potential or actual macroprudential measures
Banking sector	Sectoral systemic risk buffer (SyRB), Concentration threshold, Concentration charge, Sectoral requirements (risk weights or minimum LGD),Sectoral leverage ratio, Capital conservation buffer (CCoB), Countercyclical Capital buffer (CCyB), Borrower based measures (BBMs), NSFR-LCR, Syetemic bank buffers (G-SII/O-SII)
Disclosures	**Non-Financial Reporting Directive** (NFRD): The proposed Corporate Sustainability Directive (CSRD) will increase the coverage sustantially with for instance the share of turnover increasing form 47% to 75% and the report must include forward-looking, retrospective, qualitative and quantitative information in the short, medium and long term
	Prudential **disclosure for large listed banks** (Capital Requirements Regulation, CRR) and investment firms (IFR)
	Sustainable Finance Disclosure Regulation (SFDR)
Investment funds, investment firms and financial markets	**New disclosure templates** introduced by the SFDR will become mandatory from Jan 1 2023 on and introduce transparency to investors and standardisation across products Additional measures to **address concentrated CRFRs** could be investigated (consistent with banking sector) and addressing **system-wide liquidity mismatch and interconnectedness** should be targeted A future **mandatory standard for green bonds** could help to further reduce financial stability risks
Insurance sector	Similar investigations as regarding investment funds. Concentration risk as part of the s**olvency capital requirement (SCR) needs to be augmented by climate factors** **Impact underwriting**: reinsurer pricing to include climate-related presention measures aimed at reducing losses **Mitigation of macro effects** (esp. output) from catastrophes **supported by public policy action**, e.g. public-private partnership to foster reconstruction. EU wide risk management and risk pooling would also help.
Financing the transition	Measures to **redirect financial flows towards green investments** substantially **mitigates physical risks** in the longer term. The discussion about appropriate measures is still ongoing and largely rests on academical studies. Key findings are: **GSF is of limited use** and risks creating bubbles, **favour fuel penalizing capital requirements** against green supporting schemes, **capital requirements differentiating** between green and non-green, carbon-intensive assets and countercyclical capital buffers are useful to reduce emissions. Studies also find that **macroprudential policies** are useful in safeguarding the banking system **against transition ris**ks. **Green taxonomy** will also be useful in **reducing emssions** if the bonds are certified by a third party.

Source: ECB 2022

Imprint

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