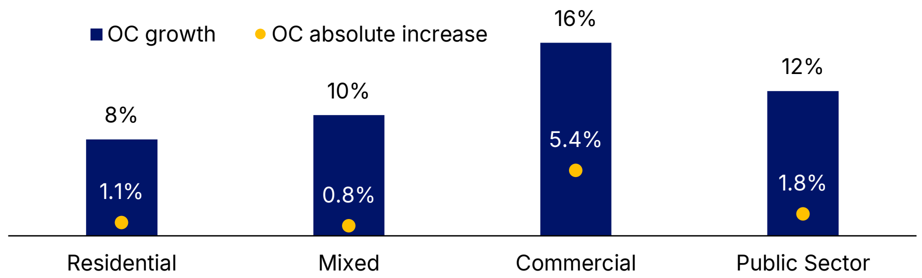
Covered Bonds: climate-change risk could demand more protection

Bold and early risk mitigation amplifies credit risks

Housing, the main collateral for covered bonds in Europe, contributes more than a third of greenhouse gas emissions, which in turn are a significant driver of climate-change risk. Incorporating climate-risk frameworks into our covered bond analysis suggests an increase of over-collateralisation (OC) may be required to support covered bond programmes. However, we do expect existing covered bond programmes to be resilient.

Scope undertook climate-change risk analysis by reviewing general climate-change risk impacts and sensitivities on the covered bond market. This entailed assessing the sensitivity of covered bond programmes globally to climate-change risk assumptions and scenarios developed by Scope based on NGFS scenarios. The general conclusions of this sector analysis led us to conclude that commercial real estate-backed covered bonds could be more impacted than other sub-sectors.

Figure 1: Increase in supporting over-collateralisation by climate risk



Source: Scope Ratings

Scope's Climate Change Risk Framework, which uses the scenarios developed by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) i.e. Orderly, Disorderly, Hot House, leads to potentially counterintuitive conclusions. Under Scope's framework, proactive climate-risk mitigation in the orderly scenario creates the highest credit stresses on mortgage covered bonds, not the Hot House scenario. This is because the orderly scenario requires market participants to bear the various costs of systemic decarbonisation in short order, creating a more immediate financial burden.

For example, residential mortgage-backed covered bonds are primarily exposed to transition risk. The Orderly scenario indicates an 8% increase of supporting OC, twice as high as the corresponding increase in the Hot House scenario, because frontloaded energy expenditure driven by increasing carbon pricing costs are weighted higher than long-term increases in physical risk. The impact of physical risk is also reduced by amortisation.

Commercial mortgage-backed covered bonds see the highest OC increases. This mainly reflects the generally lower credit quality and higher energy intensity of the underlying collateral compared to residential mortgage or public sector exposures. As such, our Climate Change Risk Framework has a greater impact on commercial exposures.

Results are different for public-sector covered bonds. Here, physical risk in the Hot House scenario drives a 12% OC increase. Unlike mortgage collateral, transition costs affect the credit quality of a sovereign's GDP and related public-sector exposures with a delay, as transition costs in the private or commercial sector will dampen economic activity.

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1. Summary of the analytical approach

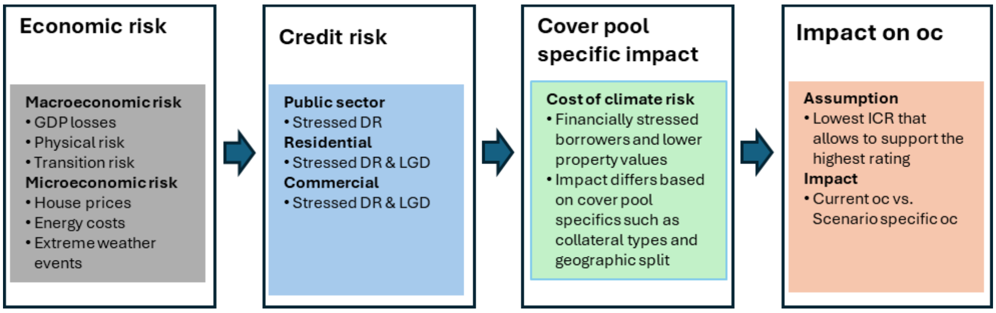
We analyse how climate risk can amplify credit-risk stresses in the underlying cover pools of covered bonds, by assessing how major borrowers and collateral types react to climate risk-related stresses and how impacts can differ across regions. Our analysis was conducted on a point-in-time basis, considering current cover-pool composition and amortisation schedules until all bonds are repaid.

Climate-change risks can be classified into physical risk and transition risk. Physical risk is more long term and encompasses impacts from chronic changes in climate (e.g. temperature change), and acute risk (e.g. increases in severity and intensity of extreme weather events such as floods, wildfires, droughts, and tropical cyclones). Transition risk will have greater impact in the short term as this is caused by the shift towards a low CO2-intensive economy and hence comes with higher energy costs and carbon taxes.

We estimated additional credit losses along three commonly adopted climate scenarios designed by the NGFS (see Appendix 1 for more details):

- **Orderly**: early introduction of climate policies, which front loads the cost of climate transition and the associated risk but limits physical risk in later years.
- **Disorderly**: later and sudden introduction of climate policies. Higher long-term transition risk because of delays or divergence across countries and sectors. Physical risk is low compared to the Orderly scenario.
- **Hot house:** no further climate policies introduced beyond what already exists. Whereas this scenario does not imply transition risk, it results in severe physical risk in later years.

Figure 2: Scope's climate stress test framework



Climate-change risk will have a direct impact on borrowers' capacity to repay their loans and will affect the collateral values to which covered bond investors have recourse in the case of borrower defaults.

We used NGFS sector GDP projections to estimate output gaps. Using panel regressions, we related them to historical observed changes in annual default rates as reported in the European Banking Authority's Risk Dashboard. For corporate and residential real estate borrowers, those changes are added to the stresses from our covered bond rating methodology. For residential real estate borrowers, we additionally model a value haircut based on energy costs and exposure to extreme weather events.

For public-sector exposures, we used NGFS assumptions to stress relevant variables in the quantitative models that are part of Scope's sovereign rating methodology and allow a stressed sovereign rating to be derived. Using a stressed sovereign anchor, we apply a notching framework to assess the credit risk of other eligible public-sector exposures.

2. The varied price of climate discipline

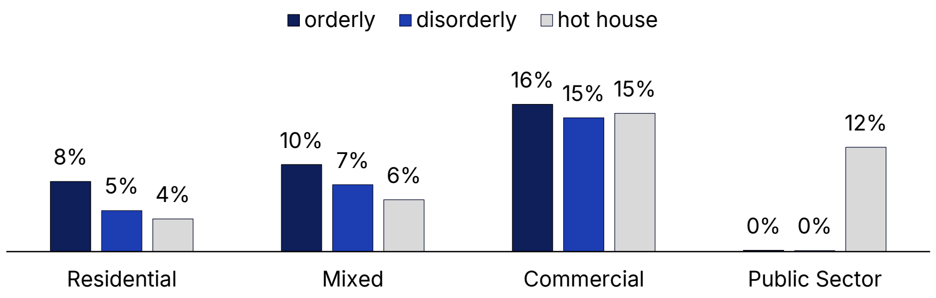
Climate-risk impacts are not uniform, they vary by asset class, region, and scenario. Early and proactive climate action is socially desirable, but it can frontload financial stress. For covered bonds, this is reflected in higher over-collateralisation (OC) requirements. Conversely, delayed or insufficient action may reduce short-term credit stress but increases long-term vulnerability.

2.1 Residential: the brave path comes at twice the over-collateralisation

Residential mortgages are the main collateral for covered bonds. In the orderly scenario, climate-change risk can be expected to increase supporting OC by 8% with differing absolute impacts between countries, ranging from 0% in Finland to 3.6% in Germany, with an average of 1.1%. This is the highest increase among the three NGFS scenarios.

The 8% impact of the orderly scenario is double the 4% increase under the Hot House scenario. This highlights a key conclusion: early and proactive climate-risk mitigation, while positive from a social perspective, can create the highest credit stresses in the short term. For mortgage covered bonds, the orderly scenario creates the highest credit stresses as it assumes an immediate impact on energy and, most importantly, carbon taxation costs.

Figure 3: Increase in supporting over-collateralisation driven by climate risk
by NGFS scenario and collateral type



Source: Scope Ratings

Stressed property prices in our climate-risk analysis (reflecting property values today net of the costs needed to improve energy efficiency to compensate for rising taxes or other carbon costs) reflect rising energy costs. Properties that have average or poor energy performance (EPC) grades will suffer most. Improving energy efficiency means that costs are frontloaded, while the benefits from lower exposure to physical risks (e.g. lower energy bills but also lower exposure to climate-change-driven natural disasters) are backloaded.

The Hot House scenario creates the highest social cost but is almost neutral for mortgage collateral. It does not introduce any relevant upfront transition costs for borrowers and thus no meaningful affordability shocks. Valuation impacts from physical risk often only occur after a cover pool has already undergone significant amortisation. The same rationale applies in the disorderly scenario, which assumes no action for the upcoming 10 years but increasing transition costs thereafter. Also stresses here only become relevant after cover pools have significantly amortised.

2.2 CRE hit highest reflecting higher energy intensity

Cover pools backed by commercial real estate (CRE) are the hardest hit and impacts do not differ significantly between NGFS scenarios. Compared to residential collateral, credit-risk drivers are amplified for default probability as well as loss severity. We applied the same assessments for CRE as for residential mortgage collateral to identify the stresses on loss given default.

Higher energy intensity stretches debt-service capacity and depresses collateral values more significantly, reflecting frontloaded carbon costs and higher energy intensity. Even more, most commercial real estate-backed loans do not amortise but are bullet facilities, which may make longer-dated stresses more relevant.

2.3 Public sector covered bonds most exposed to the Hot House scenario

Climate risk could contribute to an average 12% increase in OC for public sector covered bonds. This is driven by the Hot house scenario, which is the central and most relevant scenario for public-sector exposures. Unlike mortgage collateral, transition costs only implicitly affect a sovereign's GDP, because transition costs in the private or commercial sector will weaken economic activity and hit the sovereign's credit quality only with a delay. As a consequence, impacts from the orderly or disorderly scenarios only yield insignificant impacts to supporting OC levels.

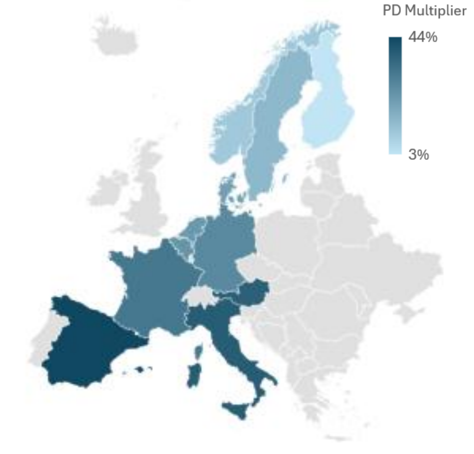
But the impact on sovereign and other public sector collateral is far from uniform. Climate change affects macroeconomic fundamentals through multiple channels. Transition shocks such as carbon taxation can weigh heavily on high-emitting industries and households, dampening GDP growth. On the other hand, increases in carbon taxation can be a significant revenue stream, especially in scenarios assuming a large ramp-up of carbon taxes. Chronic physical risks (like rising temperatures) and acute events (floods and wildfires) can further strain public finances, especially when governments absorb some disaster-related costs.

These combined pressures increase stress on sovereign ratings and other public-sector exposures and as a consequence implies increased default risk for cover pools. In contrast to mortgage covered bonds, loss given defaults are less impacted by climate risk. Stressed recoveries may be low given the lack of dedicated collateral to which investors have recourse. Most stresses result from bond restructurings and resulting NPV losses. The result is a unique long-term vulnerability for public sector collateral.

2.4 Southern European cover pools most sensitive to climate risk-induced affordability shocks; Germany leads on house-price vulnerability

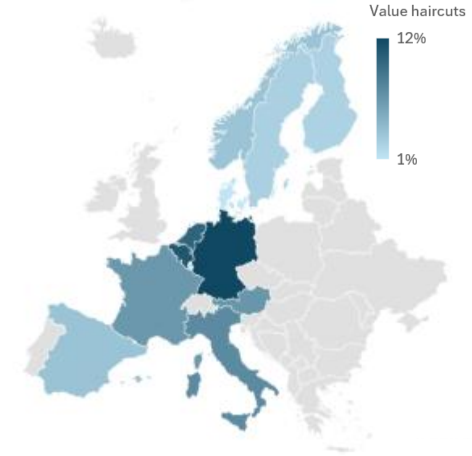
There are significant regional differences in climate risk-induced affordability shocks for residential cover pools. Southern European countries show the highest increases in affordability shocks, led by Spain where climate risk could push up borrower probability of default by 44% (based on a sample portfolio with a weighted average life of 14.5 years). In contrast, northern countries such as Finland show minimal impact, with climate risk-driven increases only increasing our stressed defaults by 3%. Geographic differences reflect the fact that in southern Europe transition risk-driven affordability shocks are more relevant due to lower disposable income.

Figure 4: Climate risk driven PD mulitplier



Source: Scope Ratings

Figure 5: Climate risk driven value haircuts



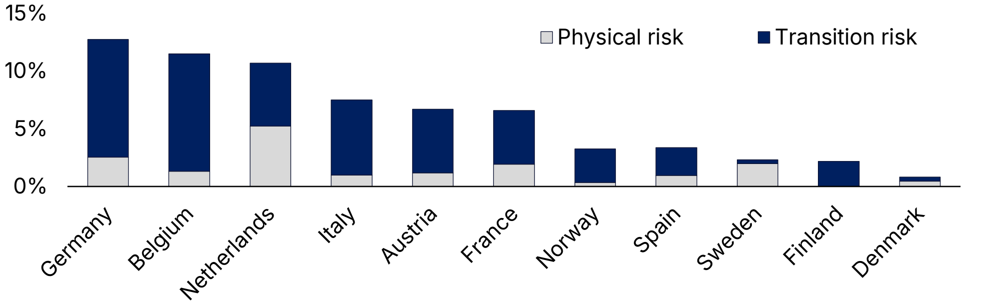
Source: Scope Ratings

Climate-risk-driven impacts on house prices are more pronounced in central Europe. We see increased valuation haircuts of 6% on average. The steepest declines are in Germany (12%), Belgium (11%), and the Netherlands (10%). Introducing climate-change risk pressures property values because of the high share of low-efficiency housing stock and capex backlogs. Nordic countries are the least affected by global warming so exhibit lower impacts. And also because renewables and biofuel resources account for a major share of household energy consumption, which reduces offsetting carbon costs.

Transition risk contributes roughly 75% of climate risk-related haircuts. Even within physical risk, which accounts for the remaining 25%, the drivers are not uniform and vary by geography. The Netherlands faces significantly higher physical risks due to land subsidence and sea-level rise, while Sweden and Spain are mostly exposed to wildfire risk.

Figure 6: Additional house price declines from transition and physical risk

by risk type and location (14.5y WAL, orderly)



Source: Scope Ratings

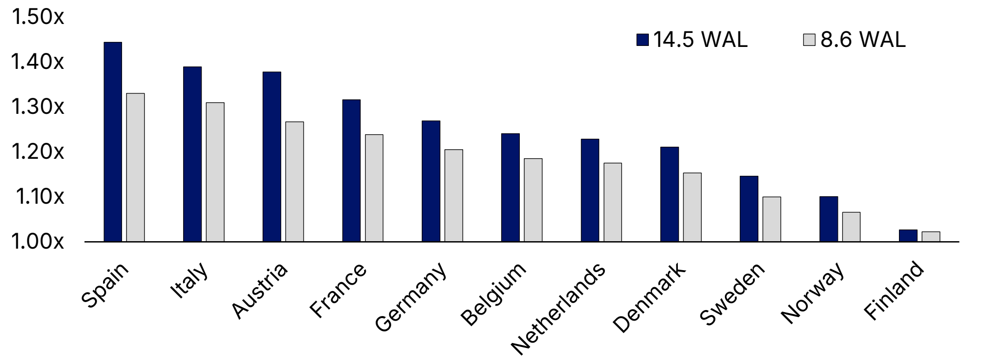
2.5 The impact of climate-change risk depends on structural mismatches

A full assessment of climate-change risk needs to go beyond pure credit risk i.e. increases in default probabilities or declines in property values. To assess the impact on supporting OC, differences in maturities, interest rates, or currency exposures also need to be assessed as they can amplify or dampen the effect of climate-related credit stresses. In particular the remaining term and repayment schedule of cover pools can play a critical role in determining the magnitude of climate-risk impacts.

Shorter weighted average lives (WALs) reduce exposure to transition-driven affordability stresses. Across a sample portfolio, the increase in PD in Spain drops to 33% from 44% if the WAL reduces to 8.6 from 14.5 years.

Figure 7: PD multiplier assuming same pools but different WALs and specific climate stress

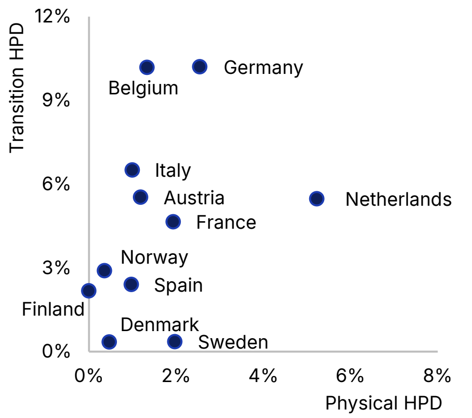
by WAL and location (Orderly scenario only)



Source: Scope Ratings

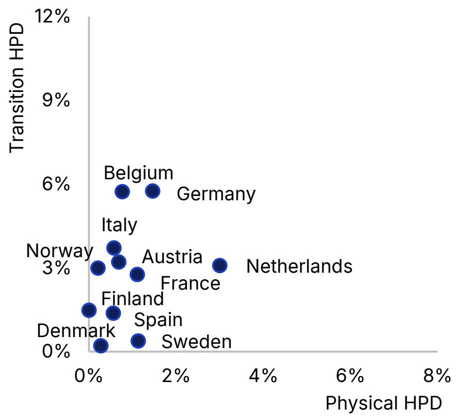
This applies to transition and physical risks alike: both declines depend on a portfolio's risk horizon. For example, shorter WALs result in proportional reductions in the magnitude of house-price decline (HPD) haircuts, illustrated by a 40% fall in property haircuts when reducing a portfolio's WAL by 40%.

Figure 8: Climate risk induced HPD for a portfolio with a WAL of 14.5 years



Source: Scope Ratings

Figure 9: Climate Risk induced HPD for a portfolio with a WAL of 8.6 years



Source: Scope Ratings

This underscores the importance of portfolio structure, and remaining term when assessing climate-risk exposure for covered bonds.

NGFS scenarios also include climate risk related-market stresses, in particular interest-rate stresses. These are not expected to drive OC sensitivities as market-risk stresses as per our Covered Bond Rating Methodology are significantly higher.

More broadly, our WAL observations highlight a salient challenge in incorporating climate dynamics into finance decision-making and credit analysis: risk/return equations are not only across horizons that challenge established market practice but also require simultaneous solving for a wide range of factors, which the most analytical tools tend not to combine. In a sense, a truly effective climate response would allow financial market participants to fully reconcile these disparate horizons and perimeters.

3. Climate risk: a moving target at society's discretion

Assuming European economies follow the trajectories described in the Orderly scenario, covered bond sensitivity to climate-change risk may already have peaked. This would be the case if European economies continue to prepare for climate-risk challenges and become more resilient to climate risk.

But political priorities have started shifting. What was perceived as an unstoppable movement is seeing a significant slowdown and has already found its way into legislation via the Omnibus package. This will weaken the impact of the Orderly scenario and make the Disorderly or Hot House scenarios more relevant. Global warming will shift higher OC requirements into the future.

The relevance of climate-change risks in covered bonds will ultimately depend on society's decisions as to if or when climate neutrality is to be achieved, and what price signals will change in the market as a result. As a result, climate risk remains a function of the level and timing of transition costs, as well as the magnitude and mitigation of physical risks.

Analytical limitations

We do not expect climate-risk scenarios to become a central and OC driving scenario in our covered bond risk analysis. But we do expect increased transparency into cover-pool sensitivity to NGFS central scenarios. Climate risk is a moving target as is its relevance in covered bond risk analysis. Its impact will depend on the social and regulatory path toward climate neutrality and relevance for investors.

Given our analytical focus on energy costs and carbon taxation, our analysis of transition costs largely disregards investments made by households to compensate for future transition costs. While this may be a fair assumption for static portfolios due to stretched affordability after house purchases, it may be too conservative for pools securing covered bonds. This is because cover pools are exposed to many vintages representing originators' loan books and accordingly also the lifecycle of mortgage borrowers (from first buyers to borrowers remortgaging for renovation). In addition, new mortgages secured by new or refurbished properties, which benefit from better EPC grades, will be constantly added and make up a larger part of the cover pool over time.

Our current assessments largely exclude the impact of long-term physical risks due to the limited lifetime of amortising mortgages. For replenished pools, physical risks may arguably warrant full consideration from the outset. Take Sweden: while transition risk is minimal, up to 85% of climate-related risk may stem from future physical hazards like wildfires and flooding. This risk is gradually materialising over time but is currently not a driving factor due to the limited WAL.

In addition, the lack of granularity for some key variables also has an impact. Robust analysis would at-best require street-level geographic information about collateral to better cater for risks such as flooding. The lack of fully comparable or not even publicly available EPC scores means that analysis often relies on average energy consumption of property types for the respective country. Cover pools from issuers that are more exposed to certain geographic areas or have less energy-efficient collateral and which only provide high-level stratified information might suffer more from higher default risk and lower recoveries than assumed in this analysis.

It is also important to note that most outstanding covered bond programmes have a weighted average life of just 3–7 years. This short risk horizon is captured in our current approach. However, despite short weighted average lives, some programmes might have very long-dated covered bonds that might ultimately be more exposed when most of the collateral has fully amortised.

Appendix 1. Scenario narratives

1. NGFS Scenarios

We analysed climate risks based on three NGFS scenarios. These scenarios are designed to provide a common basis for analysing climate risks for economies and the financial system, with a consistent set of variables and assumptions for analysing climate risks. The NGFS defines the three scenarios as follows[1]:

- **Orderly** scenarios assume climate policies are introduced early and become gradually more stringent. Both physical and transition risks are relatively subdued. Within this category we adopt the Net Zero 2050 scenario.
- **Disorderly** scenarios explore higher transition risk due to policies being delayed or divergent across countries and sectors. For example, carbon prices are typically higher for a given temperature outcome. Within this category, we adopt the Delayed transition scenario.
- **Hot house** scenarios assume that climate policies are implemented in some jurisdictions, but global efforts are insufficient to halt significant global warming. The scenarios result in severe physical risk including irreversible impacts like sea-level rise. Within this category, we adopt the Current Policies scenario.

Figure 10: NGFS scenarios at a glance

Scenario	Physical risk	Transition risk			
	Global warming	Policy reaction	Technological change	Carbon dioxide removal	Regional policy variation
Orderly	1.4°C	Immediate and smooth	Fast change	Medium-high use	Medium variation
Disorderly	1.6°C	Delayed	Slow then very fast change	Low-medium use	High variation
Hot House	3°C+	No ramp up in policies	Slow change	Low use	Low variation

Note: The cells in the table are coloured based on associated macroeconomic risks as determined by the NGFS with lower (green), moderate (yellow), and higher (red) risks.
Source: Network for Greening the Financial System

[1] Network for Greening the Financial System (2022), NGFS Scenarios for central banks and supervisors.

Appendix 2. Applying climate-related credit losses in covered bond analysis

Scope's Climate Change Risk Framework allows climate-change risk to be integrated into our analysis of covered bond credit and market risk and is summarised in Figure 2. Starting from physical and transition risk, macroeconomic and asset-specific shocks emerge. Shocks to GDP translate into affordability shocks for borrowers and physical and transition risk to recovery expectations. This increase in credit-risk measures can increase OC requirements and may prompt issuer to increase protection to maintain the highest ratings.

2. GDP losses

NGFS version 5 data contains projections of GDP trajectories and output losses due to chronic physical risk and transition risk for each of the scenarios, as well as a no-climate change counterfactual, which models how respective GDPs would evolve in the absence of shocks stemming from climate risks. Figure 11 describes the climate-risk shocks we consider to GDP:

Figure 11: climate-related shocks to GDP

Risk category	Shock	Model	Quantile	Weight
GDP shocks from Physical risk	Chronic physical risk	Nigem NGFS phase 5	Median	100%
	Acute physical risk : floods	Nigem NGFS phase 4.2	Median	50%
	Acute physical risk : drought	Nigem NGFS phase 4.2	60th	50%
	Acute physical risk : heatwaves	Nigem NGFS phase 4.2	60th	50%
	Acute physical risk : cyclones	Nigem NGFS phase 4.2	60th	50%
GDP shock from transition risk	Transition risk	Nigem NGFS phase 5	Median	100%

The NIGEM model[2] has a changing time horizon. It starts in 2022 for NGFS data version 5 and in 2021 in version 4. In order to make the data comparable with our Integrated Assessment Models (IAM) input data, we rebase the NIGEM data as follows:

- We rebase the starting year to 2020 by subtracting $(start\ year_{nigem} - start\_year_{IAM})$ from every year in NIGEM
- As this operation leads to a period stopping short of 2050, we extrapolate data NIGEM at the end of the period by considering the last available year.

We chose the 60th quantile for some indicators, when the median was not available.

The no-climate change counterfactual can be interpreted as a potential GDP evolution, whereas additional GDP losses stemming from chronic and acute physical risk, and transition risk provide a shock to this potential GDP baseline. By dividing by potential GDP, we obtain a measure comparable to an output gap, which we can project out to 2050:

$$output\ gap_{i,s,t} = \frac{GDP_{i,no\ cc,t} - GDP_{i,s,t}}{GDP_{i,no\ cc,t}}$$

For country i, scenario s and time t. Or, more explicitly,

$$output\ gap_{i,s,t} = \frac{w_{chronic} chronic\ GDP\ loss_{i,s,t} + w_{acute} acute\ GDP\ loss_{i,s,t} + w_{transition} transition\ GDP\ loss_{i,s,t}}{GDP_{i,no\ climate\ change,t}}$$

3. Stressed Default Probability

3.1 Retail and corporate borrowers

We start by calibrating the historic relation between output gaps and annual default rates (ADR) by estimating a sensitivity of default rates to sectoral output-gap shocks. Sensitivities to shocks in output gaps are based on panel regressions using DRs as reported in the EBA's risk dashboard and output gaps from the IMF's World Economic Outlook for a panel of 39 countries for different segments of corporates and retail borrowers.

[2] NiGEM is a global macroeconomic model developed by the National Institute of Economic and Social Research (NIESR) in London used for economic forecasting, scenario analysis and stress testing. In the context of NGFS it is used to assess the economic consequences of climate risks; see here.

We estimated results for secured and unsecured retail by estimating the following regression with OLS:

$$\frac{DR_{i,k,t}}{\overline{DR_{i,k}}} = \alpha + \beta_k * \ output\ gap_{i,t} + \tau_t + \gamma_i$$

For country i, segment k, and time t. τ_t is a year fixed effect and γ_i a country fixed effect, and β_k is the sensitivity of DR for segment k to changes in the output gap. Table 2 reports the results of our regressions.

Figure 12 describes our sensitivity parameters. Most of these are based on the results of the regression analysis mentioned above, except for corporate DR sensitivity, which we set at 20, based on our empirical research of the relation between bankruptcy rates and output gaps in the context of CLOs. For SMEs, we use the same ADR sensitivity as corporates for unsecured loans, whereas for secured SME loans we use the same ADR sensitivity as secured retail loans. The ADR sensitivities are shown in table 6.

Figure 12: ADR sensitivity parameters

Segment	ADR sensitivity
Corporates	20
Corporates - Of Which: SME	20
Retail – Other Retail	17
Retail – Secured on Real Estate Property	7
SME – Secured on Real Estate Property	7

This allows us to define a stressed annual default rate in function of sectorial output gaps:

Based on these sensitivities, and output gap projections, we can compute stresses to our LGDs. For retail exposures, assuming that $Base\ LGD_{i,k,t}$ is the base ADR assumption for country i, segment k, and year t, we define the stressed ADR as:

$$Stressed\ ADR_{i,k,s,t} = Base\ ADR_{i,k}\ x\ ADR\ multiplier_{i,k,s,t}$$

$$ADR\ multiplier_{i,k,s,t} = (1 + output\ gap_{i,s,t}\ x\ ADR\ Sensitivity_k)$$

For country i, segment k, scenario s and time t.

3.2 Public sector borrowers

Our approach to estimating sovereign and public-sector default projections is different than for retail and corporate portfolios. We start from Scope Group's Sovereign Rating Methodology, and stress a number of variables from the Sovereign Quantitative Model (SQM), (GDP per capita (PPP), Nominal GDP, Real GDP Growth, Inflation Rate, Primary Balance / GDP, Gross debt / GDP) by adding the shocks coming from NGFS projections in the short, medium and long term, on GDP and inflation to the SQM baseline.

The result is a stressed sovereign rating for each of the scenarios and time horizons, and we then translate this stressed rating into a notch impact by comparing the stressed sovereign ratings with their baseline rating. By using Scope's idealised expected loss and default probabilities, we then convert the notch impact into an additional default rate (ADR) for different maturities:

$$Additional\ ADR_{i,m,s,t} = f_m(base\ rating_{i,t} + \Delta\ notch_{i,s,t}) - f_m(base\ rating_{i,t})$$

For country i, maturity m, scenario s and time t. f_m is the function converting a rating X to an m-year default probability based on Scope's idealised default probability tables.

4. Stressed Loss Given Default

4.1 Retail and corporate borrowers

Starting from economic losses, we obtain stressed LGD metrics for corporate and retail sector borrowers. For corporates, we start by calibrating the historic relation between output gaps and annual default rates (ADR) and loss given default (LGD) by estimating a sensitivity of corporate LGD to sectoral output gap shocks.

Sensitivities to shocks in output gaps are based on panel regressions using DRs and LGDs respectively as reported in the EBA's risk dashboard and output gaps from the IMF's World Economic Outlook for a panel of 39 countries for different segments of corporates and retail borrowers. A caveat in this analysis is that LGDs reported in the EBA's risk dashboard already contain a downturn adjustment may present a possible bias in our estimated LGD sensitivity to economic shocks.

We estimated results for corporates, SME unsecured loans, and secured and unsecured retail by estimating the following regression with OLS:

$$\frac{LGD_{i,k,t}}{LGD_{i,k}} = \alpha + \beta_k * \ output\ gap_{i,t} + \tau_t + \gamma_i$$

For country i, segment k and time t. τ_t is a year fixed effect and γ_i a country fixed effect, and β_k is the sensitivity of LGD for segment k to changes in the output gap. Figure 13 reports our LGD sensitivity parameters. For secured SME loans, we use the secured retail LGD sensitivities.

Figure 13: LGD sensitivity parameters

Segment	LGD sensitivity
Corporates	-0.03
Corporates - Of Which: SME	-3.64
Retail – Other Retail	-3.4
Retail – Secured on Real Estate Property	-3.2
SME – Secured on Real Estate Property	-3.2

Based on these sensitivities, and output gap projections, we can compute stresses to our LGDs. For retail exposures, assuming that $Base\ LGD_{i,k,t}$ is the base LGD assumption for country i, segment k, and year t, we define the stressed LGD as:

$$Stressed\ LGD_{i,k,s,t}\ =\ Base\ LGD_{i,k,t}\ x\ LGD\ multiplier_{i,k,,s,t}$$

$$LGD\ multiplier_{i,k,s,t} =\ \ (1 + output\ gap_{i,s,t}\ \ x\ LGD\ Sensitivity_k)$$

For country i, segment k, scenario s and time t.

5. Applying climate risk stresses to real estate collateral

Climate-change risks can have a material impact on residential real estate, and as such on valuation and prices. On transition risk, carbon and energy prices can have a serious impact on real-estate prices. In particular, increases in usage costs of existing buildings may incentivise users to look for more energy-efficient buildings, unless house prices or rents also decrease to compensate for these additional costs.

Physical risks for buildings mainly result from increases in intensity and severity of acute events such as wildfires or floods. Therefore, for buildings in high-risk locations, insurance premiums will increase for properties to compensate for the expected increases in damage. These higher costs and the resulting cost differential compared to those properties that are not or less exposed also lead to changes in property values.

5.1 Transition risk

In the context of residential real estate, the main transition risks are:

- Rising costs for carbon-intensive key emission sources and indirect emissions (energy issues)
- Stricter building and reporting standards
- Changes in demand trends because of slowly shifting market preferences
- Increasing public pressure towards real estate companies concerning decisions about decarbonisation actions

We focus on this first effect as we can plausibly quantify it based on actual energy consumption data, and projections of energy and carbon prices.

Whereas building and reporting standards play a role in the evolution of residential building prices, but we assume that regulation is already considered in the analysis. Future regulation is quite uncertain and therefore is not considered when proposing quantitative stresses. The final two risks could have an impact, but it is hard to quantify so we exclude them from our analysis.

The methodology to obtain our stress consists of the following steps:

- Step 1: Compute the average surplus cost of energy use for different sources of energy per kWh due to changes in carbon and energy price changes
- Step 2: Calculate the average surplus cost of energy use per m^2 according to different factors as following: EPC, energy mix, and surplus costs per kWh
- Step 3: Compute an NPV of surplus energy and carbon costs
- Step 4: Obtain house prices per m^2
- Step 5: Compare surplus cost NPV to actual house prices

These steps are elaborated below.

5.1.1 Surplus cost per kWh

To understand the impact of carbon prices, we obtain the carbon content in kg CO2eq per kWh of different energy sources (electricity, natural gas, oil, coal, solid and liquid biomass). For all sources but electricity, we use a fixed carbon content parameter from the IEA. These can be found in Appendix 2. For biomass, we put the carbon content at zero as carbon emissions are compensated by the production of biomass.

For electricity, the carbon content depends on the source. As our scenarios have different projections as to the mix of power generation, we create a carbon intensity pathway for each scenario by dividing the carbon emissions by electricity production by electricity produced from the NGFS projections:

$$carbon\ content_{c,s,elec,t} = \frac{carbon\ emissions_{c,s,elec,t}}{electricity\ production_{c,s,elec,t}}$$

For country c, scenario s, and year t.

We then use carbon price projections from NGFS to obtain a carbon price per kWh for each energy source.

$$carbon\ cost\ per\ kwh_{c,s,e,t} = carbon\ price_{c,s,t} * carbon\ content_{c,s,e,t}$$

For each country c, scenario s, energy source e and year t.

We also obtain energy price projections per kWh from the NGFS for each of the aforementioned energy sources.

We compute a surplus energy and carbon price cost per kWh for each energy source as the difference of energy price per kWh and the carbon cost per kWh respectively in a given year and the base year.

$$\Delta energy\ price\ per\ kwh_{c;s,e,t} = energy\ price_{c,s,e,t} - \ energy\ price_{c,e,base\ year}$$

$$\Delta carbon\ cost\ per\ kwh_{c,s,e,t} = carbon\ cost\ per\ kwh_{c,s,e,t} - \ carbon\ cost\ per\ kwh_{c,e,base\ year}$$

For each country c, scenario s, energy source e and year t.

We add surplus energy and carbon cost per kWh to have an overall surplus cost per kWh for each energy source.

$$surplus\ cost\ per\ kwh_{c,s,e,t} = \Delta carbon\ cost\ per\ kwh_{c,s,e,t} + \ \Delta energy\ price\ per\ kwh_{c,s,e,t}$$

For each country c, scenario s, energy source e and year t.

5.1.2 Characterisation of energy use per square meter

After obtaining a surplus cost per kWh for each energy source, we now characterize the annual energy use of buildings in kWh per m² by type of energy source. This can greatly differ depending on the energy efficiency of buildings, as well as the energy mix used in the respective country.

We use the EPC as a proxy for energy efficiency and obtain an average consumption of energy per m² for each EPC band based on a mapping done by EDW[3]. We also compute an average annual energy consumption per m² for residential buildings based on the Building stock observatory from the European Commission.

To understand which energy sources are used, we obtain a national energy mix (in %) is based on residential energy use from Eurostat. Multiplying the energy mix proportions with the total use per kWh gives us an annual energy use per m² for each energy source:

$$annual\ energy\ use\ per\ m^2{}_{c,s,e,l} = proportion\ in\ energy\ mix_e * energy\ use\ per\ m^2{}_{c,s,l}$$

For each country c, scenario s, energy source e and energy efficiency level l. We assume that no energetic renovations will take place, and that this energy use remains stable over the period.

5.1.3 Present value of energy use surplus costs

Based on our surplus cost per kWh and energy use per square m² for every energy source, it is possible to compute an annual surplus cost per m² (ASC) when we assume that the energy use remains constant over time:

$$\mathrm{ASC}_{c,s,l,t} = \Sigma_{e \in E} annual\ energy\ use\ per\ m^2{}_{c,s,e,l} * \text{surplus cost per kwh}_{c,s,e,t}$$

For each country c, scenario s, year t and energy efficiency level l. As we are mainly interested in the property buying market and assume buildings will be used for several years, a prospective buyer will not only be interested in the increased energy costs for the year in which he buys the building, but lifetime costs. Hence, we assume the buyer will compute a present value of future annual surplus cost per m² (PVASC).

$$PVASC_{c,s,l,t} = \sum_{n=t}^{t+T} \frac{\mathrm{ASC_{c,s,l,n}}}{(1 + r_{c,s,t})^n}$$

For each country c, scenario s, year t and energy efficiency level l. T is the present value period, and $r_{c,s,t}$ the discount rate for country c, scenario s, and year t. More specifically, $r_{c,s,t}$ is the sum of the policy rate in country c and the change in long term interest rate coming from NiGEM for each country c, scenario s, and year t.

$$r_{c,s,t} = policy\ rate_{c,t=0} + change\ in\ longterm\ interest\ rate_{c,s,t}$$

5.1.4 Property prices

At the same time, we gathered the house prices of residential buildings in European countries. These values cover different geographical levels (NUTS 0 to 3) and for some, we already have it per type of building i.e., apartment or house.

Starting with the most granular level we compute the **aggregated average**, meaning starting from NUTS 3 to NUTS 0. When one price per type is unknown, we take that of one of the other types. Meaning if the apartment prices are not available, we take house prices. When one value per level is unknown, we take the first one available by ascending order of NUTS level. In case the average house price per m² is not available for the starting year, we use the national House Price Index (HPI) from Eurostat to extrapolate the house prices using the closest available year. Appendix 3 provides the sources for computing house prices per country.

5.1.5 Computation of transition stress

We obtain the surplus cost per m² by combining the surplus cost per kWh and the use in kWh/m² for each energy source. We then divide this by the annual rent per m², to come to a stress as % of the yield:

$$transition\ stress_{c,s,l,t} = \frac{PVASC_{c,s,l,t}}{Price\ per\ m_c^2}$$

For each country c, scenario s, energy source e, energy efficiency level l and year t.

[3] For Luxemburg we make a distinction for flat and houses. In Belgium, an EPC is only available per region (Brussels, Wallonia & Flanders). We compute a synthetically average EPC band for Belgium as a population weighted average of the regions.

5.2 Physical risks

Physical risk can lead to more frequent and severe extreme weather events, which can lead to higher damage costs to buildings. In order to compensate for those rising damage costs, we expect insurance premiums to go up, which leads to increased costs for buildings exposed to these risks.

We analyse the following acute physical risks:

- River flood (flood depth in m)
- Coastal flood (flood depth in m)
- Wildfire (temperature in °C)
- Tropical cyclone (wind speed in m/s)
- European windstorms (wind speed in m/s)
- Subsidence (mm/year)

We assume that the risks of natural disasters are independent and can be added.

For each of these risks, we analyse how the intensity and severity may change in different climate scenarios. Then, using standardised damage functions, we convert these events into an expected annual damage (EAD) for a set of grid cells with a high resolution (1 km by 1 km for some risks, up to 15km by 15km for some others).

$$EAD_{u,r,s} = \Sigma_{y \in Y}\ probability_{u,y,r,s} * impact_{u,y,r,s}$$

For each grid cell u, risk r and scenario s. $\Sigma_{y \in Y}\ probability_{u,y,r,s} = 1$ for each, u, r & s.

Assuming that historical average damage is already reflected in the price of a building, we compute additional damages as the difference of a projected risk damage and the historical damage:

$$Additional\ EAD_{u,r,s} = EAD_{u,r,s} - EAD_{u,r,historical}$$

For each grid cell u, risk r and scenario s.

The precise computation depends on the risk type. The data is obtained from Scope ESG.

Whereas these risks are provided on a granular level, we aggregate the data by weighing the risks by population on several administrative levels (LAU and NUTS (see glossary)). In case the location of a building is known, we can use the granular data. Otherwise, we use the most granular administrative level available.

$$Additional\ EAD_{U,r,s} = \frac{\Sigma_{u \in U}\ pop_u * EAD_{u,r,s}}{\Sigma_{u \in U}\ pop_u}$$

For each administrative unit U, risk r, scenario s and $u \in U$ the set of grid cells overlapping with an administrative unit U and pop_u the population living in this overlap.

The risk described are the are an average increase in damage for the next thirty years. As we need a curve, we convert these average damage increases into a 30-year curve by assuming that the additional risk in year T is zero, and twice as high in year T+30:

$$Additional\ EAD_{U,r,s,t=0} = 0$$

$$Additional\ EAD_{U,r,s,t=30} = Additional\ EAD_{U,r,s} * 2$$

For each administrative unit U, risk r, scenario s and year t. Between these dates, we do a linear interpolation to have an average EAD which remains the same as the non-temporal equivalent.

Assuming independence between different risks, we compute the total additional EAD per year, scenario and administrative unit as:

$$additional\ EAD_{U,s,t} = 1 - \prod_{r \in R}(1 - additional\ EAD_{U,r,s,t})$$

Similar to our transition risk measures, we compute an NPV of the additional EAD for a time horizon of 20 years, as an investor in a given year will not only be concerned about the damage within the year itself but over a time horizon.

$$PVEAD_{U,s,,t} = \sum_{n=t}^{t+T} \frac{additional\ EAD_{U,s,n}}{\left(1 + r_{c,s,n}\right)^{n}}$$

For each administrative unit U, scenario s and year t.

As for the PV calculation of the transition risk, $r_{c,s,t}$ is the sum of the policy rate in country c and the change in long term interest rate coming from NiGEM for each country c, scenario s, and year t.

$$r_{c,s,t} = policy\ rate_{c,t=0} + change\ in\ longterm\ interest\ rate_{c,s,t}$$

Finally, insurers typically calculate insurance premiums by multiplying the assessed risk by a factor that accounts for profit margins and potential unexpected losses. We computed this factor by considering the average ratio of premiums earned and claims incurred for non-life insurance data from EIOPA. The stress is then defined as:

$$Acute\ physical\ loss_{U,s,t} = \Sigma_{r\in R}\ PVEAD_{U,r,s,t} * f_{insurance}$$

For each administrative unit U, scenario s and year t. $f_{insurance}$ is the insurance factor.

5.3 Combination of risks

Assuming that physical and transition risks are independent, we combine them into an overall stress for house prices, based on a house-price index (HPÏ). The stress depends on the base HPI path proposed by the analyst, the region or location (for physical risk) and associated country, and energy efficiency (for transition risk):

$$stressed\ HPI_{l,U,s,t} = HPI_{base,t}\ \times \left(1 - Transition\ loss_{c,s,l,t}\right) \times \left(1 - Acute\ physical\ loss_{U,s,t}\right)$$

For each administrative unit U, energy efficiency level l, scenario s and year t.

$HPI_{l,U,s,t}$ loses the c subscript, as each administrative unit U is associated to a single country, and as such unnecessary.

Appendix 3. Data sources

Source	Indicator	Variable	Source link
International Energy Agency (IEA)	CO_2 emissions per kWh for different energy sources	Natural gas: CO_2 content per kWh Oil: CO_2 content per kWh Coal: CO_2 content per kWh Electricity: based on carbon emissions from electricity and electricity production (in GWh) from NGFS.	
U.S. Energy Information Administration (EIA)	CO_2 emissions per kWh for different energy sources	Calculation of CO_2 emissions per kWh cost: • For gas: .185 /1e3 tons per kWh • For heating oil: 2.96 / 10.35 /1e3 tons per kWh • For coal: .185 /1e3 tons per kWh	U.S. Energy Information Administration - EIA - Independent Statistics and Analysis
NGFS: • GCAM 6.0 • MESSAGEix - GLOBIOM 2.0-M-R12, • REMIND - MAgPIE 3.3-4.8	Carbon & energy price projections And interest rate projections	Variable paths list for timeseries: • 'Price | Final Energy | Residential and Commercial | Residential | Electricity' • 'Price | Final Energy | Residential and Commercial | Residential | Gases | Natural Gas' • 'Price | Final Energy | Residential and Commercial | Residential | Liquids | Biomass' • 'Price | Final Energy | Residential and Commercial | Residential | Liquids | Oil' • 'Price | Final Energy | Residential and Commercial | Residential | Solids | Biomass' • 'Price | Final Energy | Residential and Commercial | Residential | Solids | Coal'	NGFS Phase 5 Scenario Explorer and NGFS
Exchange rates.org.uk	Average exchange rate and inflation factor	2023 average	US Dollar to Euro Spot Exchange Rates for 2023
Eurostat	Energy mix of non-residential properties	• Final consumption – other sectors – commercial and public services – energy use $Surplus\ Cost_{e,t} = Energy\ Price\ Surplus_{e,t} + Carbon\ Price\ Surplus_{e,t}$ Where Energy Price and Carbon Price in kWh and e is the type of energy and t the time in year.	Statistics | Eurostat
- European Commission: Building Stock Observatory - Norwegian building energy statistics;	Energy consumer in non-residential buildings	• Final energy consumed in non-residential buildings • Useful floor area	EU Building Stock Observatory Microsoft Word - 236_ole-gunnar.doc
European Data Warehouse	Energy use per EPC band	ECP thresholds (in kWh) depend on the country.	Revisiting "The Babel Tower Of EPC Ratings": Updated Thresholds Across Europe - European DataWarehouse
CRE ERIX Database	For the rent assumptions prices in 2023	EUR per m2 per month	RentAssumptions_cleanup.xlsx
European Commission	For NUTS region shapefiles and populations	For weighted demographic damage results	Territorial units for statistics (NUTS) - GISCO - Eurostat

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