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Luca Bartolucci (Prometeia)[1]**, Guido Luciano Genero (Intesa Sanpaolo), Maurizio Pierigè (Prometeia)**[1]**, Fabio Verachi (Intesa Sanpaolo),**

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Executive Summary

In the context of the rapid changes that have occurred in recent years, characterized by veritable 'black swans' such as the COVID-19 pandemic and extreme weather events that are occurring with increasing frequency, the issue of climate change has come into the focus of banking regulators and supervisors.

Therefore banking institutions, if they are subject to the Single Supervisory Mechanism, have been called upon to develop (and, subsequently, to integrate into their business practices) methodologies for the identification, quantification and management of such risks, mainly under the profiles of:

- Transition Risk, associated with policies undertaken by governments to foster climate change mitigation and adaptation;
- Physical Risk, associated with the occurrence of extreme climatic events and its impact on the bank's assets.

This paper analyzes one of the most significant hazards within the Physical Risk domain, which is Flood Risk. The measurement is focused on the prospective evolution of the flood events on a portfolio of mortgages secured by residential properties. The impact of this risk driver is subsequently reflected through the movement of appropriate transmission mechanisms on the LGD and PD parameters relating to the exposures in the scope.

Finally, the effect on loan adjustments is provided, by recalculating the expected losses that result from the stressed projections. The flood risk projection is executed on a long-term timeframe, developing over 3 climate scenarios up to 2050.

The choice of this hazard is due to its relevance in terms of frequency of events and harmfulness, a relevance that is confirmed by its inclusion in both the top-down climate stress testing exercises carried out by the ECB and in the bottom-up climate stress testing exercise promoted by the ECB itself in 2022 and carried out by the SSM Banks.

A comprehensive simulation framework, structured as follows, is then presented:

- a macro-climate scenario simulation engine;
- the downscaling of these scenarios to obtain localized climate effects on individual properties;
- the transmission of these effects into a depreciation formula for the individual property;
- the LGD stress associated with the devaluation of the collateral property, and the PD stress that goes along with it, obtained by correlation.

Key Words:

Climate risk, Physical Risk, Flood Risk, macro-climate scenario, LGD

Literature review

The research about the effects of flood events on mortgage portfolios is quite new, and mostly focused on American properties. Kousky et al. (2020) provide a comprehensive literature review on the topic, highlighting the low rate of (US) insured properties in areas prone to flood risks, and investigating potential behavioural reasons for this low take-up level of insurance.

In the work of Ratnadiwakara and Venugopal (2020), the relationship between flood risk exposure and lower-income borrowers is proven, as well as the higher likelihood of mortgage default for houses bought after a major flood event. Calabrese et al. (2021) proposed an additive Cox proportional hazard model with time-varying covariates to estimate the impact of the exposure to flood risk (in interaction with heavy rainfall) and tropical cyclones on mortgage default in Florida.

They also performed a scenario analysis in 2050 under RCP 4.5 scenario. The main evidence from scenario analysis is an increase in the risk of default for properties located in areas with a projected increasing exposure to flood risk. Caloia and Jansen (2021) instead proposed to carry out a flood risk stress test for the Netherlands, by estimating (with a *damage function* approach) damages to properties deriving by flooding for several return periods, which are then feeded into PD and LGD satellite models to estimate their impact on the bank's balance sheets.

This stream of research is integrated, in this paper, with a sophisticated Integrated Assessment Model (IAM) used for the long-term projection of economic and climatic variables.

The research on IAMs traces back to the seminal works of Nordhaus, who was awarded the Nobel Prize in Economics in 2018 with the following motivation *"[..] integrating climate change into long-run macroeconomic analysis"*. Indeed, Nordhaus (1991) was the first work to evaluate the feedback effects between economic activity and the climate through the GHGs emissions channel, and his prolific scientific production has widened the frontier of climate change economics (see Nordhaus (2018)).

As it is known, the feedback loop works as follows: GHG emissions are a byproduct of economic activity that affect the climate which in turns impacts economic activity through negative effects on productivity and damage to the capital stock. Further developments of this research stream (see Barrage 2020) allow for the modeling of climate transition policies, such as carbon taxes, and their distortionary effect on economic activity.

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[1] We would also like to thank our team colleagues with special reference to: Giacomo Novelli (PhD, Prometeia) and Michele Catalano (PhD, IIASA - International Institute for Applied System Analysis), who oversaw the identification of exposures and the measurement of hazard, as well as Marco Brandolini, Andrea Lugli, Cristiana Moriconi, and Luca Zanin who oversaw the vulnerability analysis and the transmission of impacts on credit risk parameters.

This type of models allows to properly estimate the welfare costs of taxing emissions against the economic costs associated with not taxing emissions, allowing GHGs to rise.
One final tool for the evaluation of the welfare effects of climate transition policies on a global scale is the use of an OLG (Overlapping Generations) model, which is able to properly discount the welfare of future generations against the costs needed for the current transition policies (Kotlikoff et al. 2019).

General framework

Following the entry into force of the Paris Agreements and the European Union's adoption of the commitment to achieve climate neutrality by 2050 ('Fit for 55'), the European financial sector is called upon to play a leading role in the ecological transition process.

From a regulatory point of view, this role is to be outlined as follows:

- on one hand, as a role in monitoring the environmental sustainability of investments, according to the technical criteria outlined in the EU Taxonomy, with the aim of directing capital flows towards 'green' activities;
- on the other hand, through the monitoring and management of environmental, social and governance (ESG) risks.

Climate risks can be divided between risks related to transition policies (such as carbon taxes, ETS price increases, energy performance constraints) and risks related to the impact of weather events, i.e. physical risks (which in turn are divided between risks related to extreme weather events, i.e. *acute* risks, and risks related to permanent changes in weather phenomena, i.e. *chronic* risks).

This paper analyses one of the most significant hazards within this last category, measuring the prospective evolution of the **flood risk on a portfolio of mortgages** secured by residential properties.

The impact of this risk driver is then reflected through the movement of appropriate transmission mechanisms on the LGD and PD parameters related to the exposures in the perimeter. Finally, the effect on impairments flows is estimated, through the recalculation of the expected loss.

The choice of this hazard is due to its relevance in terms of frequency of events and harmfulness, a relevance that is confirmed by its inclusion in both the top-down climate stress testing exercises carried out by the ECB and in the bottom-up climate stress testing exercise promoted by the ECB itself in 2022 and carried out by the SSM Banks, as well as by the availability of data (which makes possible a more punctual and reliable mapping phase, compared to other less consolidated and/or more complexly measured hazard events).

The methodology for flood risk evaluation can be broken down along the following axes:

1. Identification of **exposure**: the geographical location of properties, especially in terms of proximity to waterways
2. **Hazard measurement**: it consists of the forecast of the flood phenomenon, expressed in terms of flood depth. The forecast is calculated from the application of the IAM macroclimatic model, which estimates, among other output variables, temperatures, winds and precipitation. The forecast horizon is 2022-2050 and is based on three distinct NGFS scenarios: Orderly Transition, Disorderly Transition and Hot-House World, which were also used for the recent ECB-sponsored regulatory exercise 'Climate Risk Stress Test 2022';
3. **Vulnerability**: the vulnerability of individual exposures is derived from the characteristics of the individual property (e.g., in terms of construction material, the height of the house and the overall interior and exterior quality, etc.).

The combined analysis of these factors results produces an estimate of the expected impairment of the property under the different scenarios considered, which for the purposes of this analysis is the main stress factor for the exposure's credit risk parameters.
The final step is to recalculate the portfolio impairments with the stressed PDs and LGDs. The simulation time horizon is, consistently with the applied NGFS scenarios, 2050.
The assumption about the evolution of loan volumes is that of a static balance sheet: maturing exposures are replaced by equal volumes of new loans with the same financial characteristics. The starting portfolio consists of performing exposures exclusively.

Methodology: Exposure

The portfolio considered for the purposes of this use case consists of 8,835 residential mortgage exposures, secured by properties entirely located in Italy. The source database, extracted on data updated to 2021, provides information about:

- location (address), intended use, value of the property, "asset specific" information - if available;
- guaranteed amount and LGD of the exposure;
- PD of the entrusted counterparty.

Each exposure in the portfolio in scope is guaranteed by a single residential property; accordingly, in the remainder of this document, reference is made indiscriminately to properties and exposure lines.

As the following table shows, the portfolio is well diversified geographically across the country:

Table 1 – Geographical breakdown of properties

Region	Amount	#	Share (amount)
ABRUZZO	23.808.601	162	1,5%
BASILICATA	13.821.452	97	0,9%
CALABRIA	41.962.692	333	2,6%
CAMPANIA	167.516.597	885	10,5%
EMILIA ROMAGNA	126.059.866	719	7,9%
FRIULI VENEZIA GIULIA	38.786.340	265	2,4%
LAZIO	264.533.445	1.121	16,7%
LIGURIA	54.648.183	312	3,4%
LOMBARDIA	274.785.356	1.423	17,3%
MARCHE	26.915.106	175	1,7%
MOLISE	3.637.918	28	0,2%
PIEMONTE	64.304.739	418	4,0%
PUGLIA	131.427.410	873	8,3%
SARDEGNA	24.793.483	157	1,6%
SICILIA	22.377.485	143	1,4%
TOSCANA	148.797.334	784	9,4%
TRENTINO-ALTO ADIGE	4.509.421	18	0,3%
UMBRIA	22.976.036	169	1,4%
VALLE D'AOSTA	2.490.446	11	0,2%
VENETO	130.383.763	742	8,2%
TOTAL	1.588.535.672	8.835	100,0%

In order to provide a starting (static) representation of flood risk exposure, the aggregated portfolio is represented below according to risk clusters on a provincial basis (NUTS2), proposed by the ECB and used for the 2022 Climate Risk Stress Test.

Table 2 – Breakdown of properties by ECB risk bands

Flood Risk	Amount	#	Share (amount)
MINOR	683.217.576	3.547	43,0%
LOW	420.567.848	2.646	26,5%
MEDIUM	476.561.005	2.599	30,0%
HIGH	8.189.243	43	0,5%
TOTAL	1.588.535.672	8.835	100,0%

According to the flood risk classification established by the Regulator, four provinces[2], out of the entire Italian territory, are classified as exposed to a "High" risk.

In order to follow up on the exercise by means of the proposed methodological approach, which envisages a more granular association of the property with the territory in order to evaluate more precisely the environmental characteristics of the actual location (e.g., the individual properties are linked to the geographic cells for which the models simulate the manifestation of flood phenomena), the assets were geo-localised in order to obtain, starting from the address, the latitude and longitude.

The risk parameters (PD and LGD), to make the results more comparable by isolating only the effects of Flood Risk, have been made homogeneous for all exposures in scope, consequently the differences in PD and LGD levels obtained derive entirely from Flood Risk shocks.

Methodology: Hazard

The flood risk estimation as a physical phenomenon can be broken down into two distinct steps:

- rainfall forecasting;
- flood depth[3] estimation.

The estimation of rainfall and the consequent Flood Depth is carried out at the level of the individual property, traced back to the relevant geographical cell. Furthermore, above the whole procedure there is a top-down econometric model, i.e., an IAM model developed by Prometeia, which projects a set of macroeconomic and climatic variables over long-term time horizons (in this

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[2] Provinces of Imperia, Sondrio, Verbano-Cusio-Ossola and Aosta.

[3] The exercise is focused on flood risk events originating from river floods; sea floods events have been excluded.

specific case a projection with a time horizon up to the end of the century is considered) at a high level of geographical aggregation (national). The equations are calibrated to NGFS[4] scenario values (June 2021 release).

Following the calibration of the IAM model on the NGFS scenarios, the methodology envisages further specification of the forecasts in order to produce climatologies - i.e., geo-referenced grids of climatic data (in this case the climatic data of interest are the precipitation for the hazard event under analysis). Given the significant variability of this specific climatic phenomenon (floods), it was decided to produce the climatologies with a high granularity, defining cells of $1km^2$, to adequately capture the riskiness to flood events of individual building units.

This specification is achieved by relating the national forecasts to the SSP/RCP scenarios developed within the World Climate Research Programme[5]. At this stage an initial downscaling between the Prometeia-NGFS macro scenarios and the SSP/RCP scenarios is performed. This calculation makes it possible to use the climatologies of the SSP/RCP scenarios but calibrated to the paths of the NGFS scenarios in terms of climate variables, and to exploit their vast analytical potential in terms of geolocation of atmospheric phenomena. Downscaling can thus be defined as the process of inferring more granular climate data than the source data, covering a wider area.

To be able to use climatologies at the desired level of granularity (which, for the purpose of this paper, consists of the single property), starting from the climatologies identified in the previous point, a further step of statistical downscaling of climate metrics on the geographical cells of interest is carried out on the basis of a high granularity historical dataset[6].

This calculation process then allows a probability distribution of the flood depth to be estimated for each forecast instant, for each cell and for each scenario. The probability distribution of Flood Depth is calibrated and validated on the main global hydrogeological[7] models and is forecasted for both river flooding and urban.

From the probability distributions estimated in the previous point, for the purpose of this exercise, 5 return periods[8] were isolated: 10, 50, 100, 200 and 500 years.

Methodology: Vulnerability

Estimation of the structural depreciation of residential property

The process for estimating the theoretical depreciation of the property due to flood risk starts by translating the flood depth into structural damage of the property. For the estimation of structural impairment, the damage function library (estimated by the JRC[9] and available for Europe) is used. The function allows the theoretical structural damage resulting from flooding to be quantified based on the location of the property and certain of its characteristics. These include:

- reconstruction costs;
- vulnerable surface area (squared meters) of the property to the flood phenomenon;
- maintenance status;
- property type;
- number of floors (cadastral) of the building.

On these quantities, to allow the function to be applied even in the presence of missing information, ad hoc models were created to estimate and complete the minimum information set. Finally, to correctly assess the value of the damage over the entire time span under analysis, the results of the theoretical damage function at time t0 are projected through the use of a property price forecasting model, integrated with the IAM model.

Once the value of the damage has been simulated, this is then transformed into a percentage of devaluation through the application of a mathematical model which, combining the extent of the damage itself and the territorial specificity of the reference property market (purchase prices), calculates as a final result the monetary loss (expressed in current euros) connected to the flood event for each asset, year, scenario and return period.

Calculation of expected depreciation

The next step is to calculate the expected write-down (or loss), known in the catastrophe risk literature as the Average Annual Loss: each percentage write-down is multiplied by the respective 1-year marginal probability of occurrence.

Equation 1 – Calculation of expected Average Annual Loss

$$AAL_t\% = q_{sv}^{RP_{500}} p_{RP_{500}} + q_{sv}^{RP_{200}} p_{RP_{200}} + q_{sv}^{RP_{100}} p_{RP_{100}} + q_{sv}^{RP_{50}} p_{RP_{50}} + q_{sv}^{RP_{10}} p_{RP_{10}}$$

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[4] Specifically, of the six overall scenarios provided by NGFS in the release, those actually used are as follows: Orderly Transition – Net Zero 2050, Disorderly Transition – Delayed Transition, Hot-house world – Current Policies.

[5] Coupled Model Intercomparison Project Phase 6: https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6 .

[6] Database WorldClim.

[7] HadGEM2 Model: https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-hydrology-variables-derived-projections?tab=doc .

[8] For example, the flood depth of a flood event associated with a 500-year RP can be interpreted as the flood depth of an event occurring on average once every 500 years (in a specific location, at a specific date, in a specific scenario).

[9] Huizinga, J., De Moel, H. and Szewczyk, W., (2017). Global flood depth-damage functions: Methodology and the database with guidelines, EUR 28552 EN, Publications Office of the European Union, Luxembourg.

The result of the AAL%, calculated on the portfolio and multiplied by the appraised value of the properties in scope, allows the calculation of the average pure risk premium across the whole simulation (i.e., the "fair" insurance premium that one would have to pay to protect against flood risks in the absence of a mark-up by the insurance company). The results of this metric, calculated as the Euros required to insure 100,000€ of collateral value, are as follows:

Table 3 – Portfolio Pure Risk Premium

Scenario	Premium
Orderly Transition	4,3€
Disorderly Transition	5,2€
Hot-House World	6,0€

Following this calculation, from the AAL forecasts for each property, stressed appraisal values that include the expected effect of Flood Risk are estimated for each year and scenario. Once these appraisal values have been estimated for each simulation year, for LGD calculation purposes the expected loss calculated over an 8-year period from the date of default is estimated at each future date. This observation horizon represents a conservative estimate of the time required[10] for the workout of (secured) non-performing loans in Italy.

Methodology: Impact on risk parameters and impairments

LGD Stress

Having produced as output from the previous step a forecast of the depreciation of the property, the resulting LGD stress is calculated for each individual position, based on the cumulative depreciation of the property relative to the starting value. The formula is applied as follows:

Equation 2 – LGD stress based on collateral depreciation

$$LGD_t = LGD_0 \cdot \left(1 + \left(\frac{-(1 - LGD_0)}{LGD_0} \cdot V\%_{value_t}\right)\right)$$

where:

- $V\%_{value_t}$ is the cumulative percentage (de)growth of the appraisal value.

PD stress

As described in the previous sections, the elaboration is carried out on the basis of three NGFS-derived long-run scenarios. It should be noted that for PD stress purposes the impacts of macroeconomic variables are sterilized: the only impact considered is the impact from flood events. Therefore, the impact from flood events is calculated using a correlation formula between LGD and PD. Although the literature on this subject is still scarce, empirical evidence[11] has been found of a significant deterioration in the credit quality of real estate loan exposures following heavy flood events.
To measure the correlation between PD and LGD, we chose to apply the formula proposed by Frye-Jacobs[12], which establishes the following correlation structure between conditional LGD (denoted LGD1) and stressed PD (denoted PD^{ST}) [13]:

Equation 3 – Frye-Jacobs model

$$PD_{ST} = \frac{\Phi\left[\Phi^{-1}[PD_{ST}] - \dfrac{\Phi^{-1}[PD_{TTC}] - \Phi^{-1}[PD_{TTC} \cdot \mathrm{LGD}_0]}{\sqrt{1-\rho}}\right]}{LGD_1}$$

The basic assumption of this model is that PD and LGD are distributed according to the Vasicek[14] portfolio model and the PD_{ST} is assumed to be equal to the conditional Default Rate[15].

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[10] https://www.infodata.ilsole24ore.com/2016/04/27/npl-la-media-italiana-per-il-recupero-dei-crediti-e-7-8-anni/ .

[11] Carolyn Kousky, Mark Palim & Ying Pan (2020) Flood Damage and Mortgage Credit Risk: A Case Study of Hurricane Harvey, Journal of Housing Research.

[12] J. Frye, M. Jacobs Jr., Credit loss and systematic loss given default, The Journal of Credit Risk Vol 8, 1-32, Spring 2012.

[13] For the purposes of this exercise, no assumptions were made on the valuation of the correlation parameter ρ, which is set at zero. This choice is equivalent to removing the systematic (macroeconomic) risk factor common to all exposures in the portfolio, focusing exclusively on the idiosyncratic risk factors of individual exposures, namely Flood Depth.

[14] Vasicek, O. (2002), 'The distribution of loan portfolio value', Risk 15(12).

[15] See note 2 related to Equation (7) in António dos Santos "The relation between PD and LGD: an application to a corporate loan portfolio" - https://www.bportugal.pt/sites/default/files/anexos/papers/re202009_en.pdf

Results

To facilitate the reading of the results, the portfolio is segmented into four risk clusters. The segmentation is defined as follows:

- by sorting all exposures in the sample according to expected losses;
- by assigning to cluster "1" all exposures for which expected losses are zero;
- dividing the remaining exposures into three dimensionally homogeneous clusters.

FD_OT, FD_DT and FD_HHW denote the average Flood Depths (in meters) realized in the respective scenarios (Orderly, Disorderly and Hot-House). The outcome of the process is as follows (the values reported below refer to a Return Period of 500 years, projected to 2050):

Table 4 – Flood depth by risk clusters and scenarios

Cluster	Amount (€)	#	FD_OT (m)	FD_DT (m)	FD_HHW (m)
1	1.415.823.202	7.504	0,70	0,72	0,77
2	60.243.080	439	0,83	0,86	0,93
3	57.120.019	438	0,86	0,89	0,96
4	55.349.371	454	1,29	1,34	1,45
	1.588.535.672	8.835	0,74	0,77	0,82

Overall, we can see how the portfolio is predominantly distributed over geographic units of negligible risk, which is why they are placed in cluster 1. We also show how the risk classes established above are distributed with respect to the NUTS2 zones (provinces) identified by flood risk in the Climate Stress Test:

Table 5 – Flood depth by ECB risk classes

	# (€)	1(m)	2 (m)	3 (m)	4 (m)
MINOR	3.547	0,76	0,84	0,80	0,99
LOW	2.599	0,77	0,99	1,01	1,55
MEDIUM	2.646	0,79	0,95	1,07	1,70
HIGH	43	0,85	1,38	1,77	-

It should be noted that the results, in terms of Flood Depth forecasts, are substantially consistent, on average, with the mapping provided by the ECB: higher risk classes correspond to higher Flood Depths. Below is the numerical evidence of the exercise, in terms of stress on risk parameters and overall forecasts and adjustments.

LGD

Table 6 – Stressed LGD by scenario

ORDERLY	2021	2030	2040	2050
1	13,5%	13,5%	13,5%	13,5%
2	13,5%	13,5%	13,5%	13,5%
3	13,5%	13,7%	13,7%	13,8%
4	13,5%	14,7%	15,7%	16,8%

DISORDERLY	2021	2030	2040	2050
1	13,5%	13,5%	13,5%	13,5%
2	13,5%	13,5%	13,5%	13,6%
3	13,5%	13,7%	13,8%	14,0%
4	13,5%	15,1%	16,1%	17,4%

HOT-HOUSE	2021	2030	2040	2050
1	13,5%	13,5%	13,5%	13,5%
2	13,5%	13,5%	13,5%	13,7%
3	13,5%	13,7%	13,9%	14,1%
4	13,5%	15,1%	16,4%	17,9%

LGD stress intensity is significantly concentrated on risk cluster 4; there is a high similarity of the Disorderly and Hot-House World scenarios.

PD

Table 7 – Stressed PD by scenario

ORDERLY	2021	2030	2040	2050
1	0,67%	0,67%	0,67%	0,67%
2	0,67%	0,67%	0,67%	0,67%
3	0,67%	0,72%	0,72%	0,75%
4	0,67%	1,00%	1,33%	1,79%

DISORDERLY	2021	2030	2040	2050
1	0,67%	0,67%	0,67%	0,67%
2	0,67%	0,67%	0,67%	0,70%
3	0,67%	0,74%	0,75%	0,79%
4	0,67%	1,13%	1,49%	2,06%

HOT-HOUSE	2021	2030	2040	2050
1	0,67%	0,67%	0,67%	0,67%
2	0,67%	0,67%	0,69%	0,73%
3	0,67%	0,74%	0,77%	0,84%
4	0,67%	1,13%	1,61%	2,34%

Applying the Frye-Jacobs formula results in a high shift for PD, significantly higher than that of LGD, relative to the initial level of the respective starting points.

Balance-Sheet and Impairments

Table 8 – Balance-sheet projections and impairments, by scenario

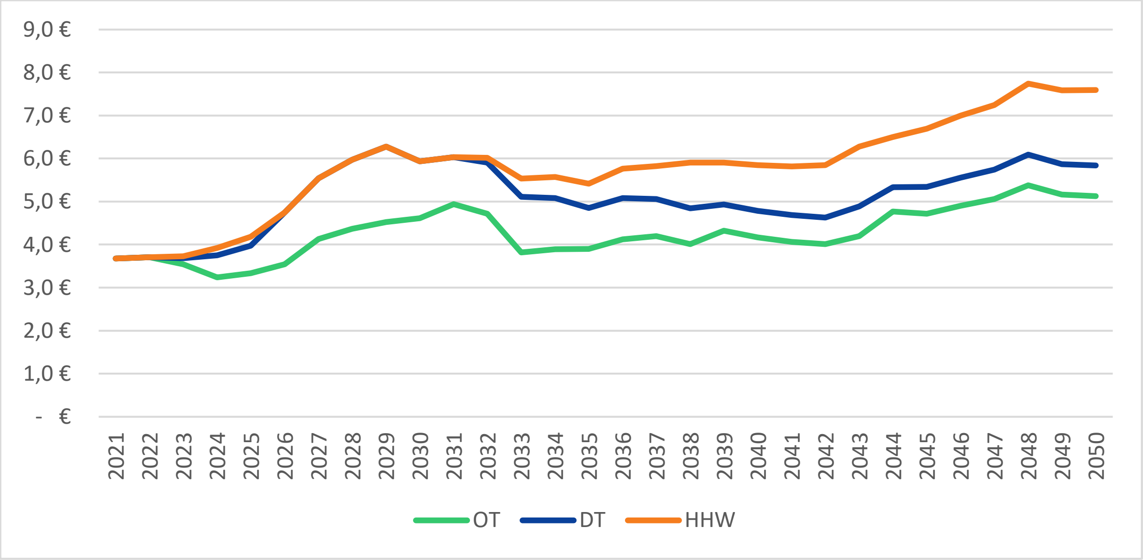
		ORD	ORD	ORD	HHW	HHW	HHW	DIS	DIS	DIS
	2021	2030	2040	2050	2030	2040	2050	2030	2040	2050
Gross Book Value	**1.589**	**1.589**	**1.589**	**1.589**	**1.589**	**1.589**	**1.589**	**1.589**	**1.589**	**1.589**
Performing	1.589	1.537	1.485	1.432	1.536	1.483	1.427	1.536	1.483	1.429
1	*1.416*	*1.370*	*1.324*	*1.277*	*1.369*	*1.321*	*1.272*	*1.369*	*1.322*	*1.274*
2	*60*	*58*	*56*	*54*	*58*	*56*	*54*	*58*	*56*	*54*
3	*57*	*55*	*53*	*52*	*55*	*53*	*51*	*55*	*53*	*51*
4	*55*	*54*	*52*	*50*	*54*	*52*	*50*	*54*	*52*	*50*
NPL	0	52	104	156	52	106	162	52	105	159
Impairments [Stock]	**4**	**28**	**58**	**87**	**29**	**59**	**91**	**29**	**59**	**90**
Performing	4	4	4	4	4	4	4	4	4	4
1	*3,4*	*3,3*	*3,1*	*3,0*	*3,3*	*3,1*	*3,0*	*3,3*	*3,1*	*3,0*
2	*0,1*	*0,1*	*0,1*	*0,1*	*0,1*	*0,1*	*0,1*	*0,1*	*0,1*	*0,1*
3	*0,1*	*0,1*	*0,1*	*0,1*	*0,1*	*0,2*	*0,2*	*0,1*	*0,1*	*0,1*
4	*0,1*	*0,2*	*0,3*	*0,4*	*0,2*	*0,4*	*0,5*	*0,2*	*0,3*	*0,5*
NPL	0	25	54	84	25	55	87	25	55	86
Coverage Performing	0,2%	0,2%	0,2%	0,3%	0,2%	0,3%	0,3%	0,2%	0,3%	0,3%
1	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*
2	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,2%*	*0,3%*	*0,2%*	*0,2%*	*0,3%*
3	*0,2%*	*0,3%*	*0,3%*	*0,3%*	*0,3%*	*0,3%*	*0,3%*	*0,3%*	*0,3%*	*0,3%*
4	*0,2%*	*0,4%*	*0,5%*	*0,8%*	*0,4%*	*0,7%*	*1,1%*	*0,4%*	*0,6%*	*0,9%*
LGD Performing	13,5%	13,5%	13,6%	13,6%	13,5%	13,6%	13,7%	13,5%	13,6%	13,6%
Impairments [Flow]	*1,62*	*2,92*	*2,94*	*3,01*	*2,99*	*3,08*	*3,26*	*2,99*	*3,01*	*3,13*

Conclusions

The main evidence from this exercise is that a large majority of the portfolio falls into the negligible risk cluster. The most exposed part of the portfolio (risk class 4) consists of 3.5% of the overall exposure: for these positions, the coverage ratio in 2050 reaches between 3 and 5 times the initial level, depending on the scenario. It also emerges that even for risk classes 2 and 3, the effect is modest overall, compared to the baseline scenario: compared to the initial level, the coverage ratio at 2050 grows between 1% and 6% for class 2 exposures, while it grows between 15% and 31% for class 3 exposures. This outcome is consistent with the Flood Depth of the respective clusters. Geographical factors and characteristics of the different real estate zones contribute to this outcome: the analytical mapping of locations and its association with climatologies allows for a more accurate grasp of the actual vulnerability to flood events.

The evidence shown in Figure 1 shows a generalized upward trend in the risk premium from around 2040 onwards, resulting in an increase in this premium in the Hot-House world scenario of around 33% compared to the Orderly Transition scenario.

Figure 1 – Evolution over time and scenarios of the pure risk premium



From a technical point of view, potential areas for refining this type of analysis include:

- to elaborate further on the correlation between portfolio defaults (and the consequent parametrization of the ρ parameter of the Frye-Jacobs model, which, if valued, would lead to more severe results in terms of increase in expected loss);
- to evolve the calibration of the depreciation formula, based on the height of the property: a flat on the fifth floor, for example, would not be directly affected by a 'standard' flood event, but its value would be affected by damage to garages, common areas located on the ground floor, and so on. To this end, it is important to enrich the source property database as much as possible to reduce the use of statistical proxies;
- to integrate real estate price forecasts according to the NGFS/ECB reference scenarios into the methodological framework, capturing their market revaluation effect;
- to explore further the transmission channels on PDs, the relevance of which, emerging from the analysis, requires further contributions / in-depth analysis;

  to integrate the management of insurance coverage on the various positions into the methodological framework and, subject to data availability, refine the PD stress methodology to distinguish the riskiness of insured positions from that of uninsured positions.

Finally, future developments of this kind of analysis are going to be determined by regulatory (Stress Test exercises, ESG Pillar III, EU Taxonomy, etc.) and managerial needs, as the Banks will progressively integrate Physical Risks measurement into the strategic and business processes. The first step, on the regulatory side, is an adequate **mapping** of the bank exposure to Physical Risk – on immovable properties and NFCs as well (e.g ESG disclosure). A further development requires banks to equip themselves with a damage estimation methodology (e.g. ICAAP), such as the one presented in this paper for real estate assets. However, to fully integrate physical risk considerations into strategic choices, it is necessary to integrate **forward-looking climatic metrics**, in strategy and business processes. A not exhaustive list of use cases follows:

1. credit allocation should take into account the trade-off between different transition scenarios: economic sectors which may are less impacted by transition impacts (say because lower energy intensive) may be adversely affected by extreme climatic events, which are going to be more frequent and damaging on a longer timeframe;

2. due to the long maturity (and consequent riskiness) of mortgage exposures a forward-looking physical risk metric should be adopted and integrated into loan underwriting process;

3. because of the need to consider the uncertainty inherent into physical risk:
    a. loans pricing should be enhanced taking into account risk exposure;
    b. opportunities linked to insurance products, which may be provided to the customers or directly purchased by the Bank, can be progressively adopted.

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