REPORT ON THE BANKING SECTOR'S EXPOSURE TO CLIMATE RISK

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METHODOLOGICAL NOTE ON THE CLIMATE SCENARIO ANALYSIS

BANCO DE PORTUGAL
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Contents

1 Overview

This note describes the projection methodology used in Section "2.2 Climate scenario analysis: credit risk of non-financial corporations" of the *Annual Report on the Banking Sector's Exposure to Climate Risk of the Banco de Portugal* (hereinafter the Annual Report). The Annual Report assesses the financial situation of non-financial corporations (NFCs) under very long-term climate scenarios, developed by the Network for Greening the Financial System (NGFS). The methodology described in this document makes it possible to obtain paths for probabilities of default (PD) and for loss given default (LGD) at firm level.

The assessment exercise benefits from a significant component of data at firm level and loan agreement level, instrumental for assessing risks, which materialise depending on the type of firm activity and its location. The projection exercise incorporates accounting information of Portuguese NFCs and the exposure of resident banks to these NFCs. To calibrate climate shocks, the physical risk exposure associated to the geographical location of firms' assets is used, as well as projections of NFCs' greenhouse gas (GHG) emissions.

The methodology used broadly follows the ECB's first top-down climate stress test (Alogoskoufis et al., 2021). As described in the Annual Report, this ECB stress test featured an unprecedented level of granular information – in terms of the geographical characterisation of climate-related risks, number of firms and banks included in the exercise – and a 30-year time horizon.

The methodological note is organised as follows. Section 2 discusses the sample of firms considered in the projection exercise, Section 3 presents the PD projection model, indicating the effects of climate risk transmission channels on firms' credit risk, and Section 4 describes the estimation of LGDs, highlighting the impact of the materialisation of physical risks on firms' physical collateral.

2 Data

The projection exercise considers the 50 thousand firms with higher loan exposure in the Central Credit Register (CCR) in December 2021. The selection of these firms used three additional criteria: (i) the firm had available data on the total amount of turnover in 2020, obtained from the Banco de Portugal's Central Balance Sheet Database (CBSD); (ii) the firm had credit risk (PD) data in 2021 produced by the Banco de Portugal's In-house Credit Assessment System (ICAS); and (iii) the firm had an overdue loans ratio of less than 25% of total exposure. Loans associated with these 50 thousand firms correspond to around 79% of total CCR loans to firms, i.e. 68% of GVA and 77% of the total financial debt of the population of firms in the CBSD.

Loans to NFCs belonging to economic groups were reallocated within the respective groups' firms, so as to observe the economic materiality of the firms' operation. For firms that are part of economic groups, individual loan exposure is equivalent to the share of the turnover of that individual firm in the economic group's total turnover.[1] This process of reallocating loans within economic groups aims to increase the economic/climate significance of exposure, preventing

[1] As for individual firms, materiality criteria were also considered for firms that are part of economic groups. Only firms of economic groups were considered, for which: (i) data on turnover were available in 2020; (ii) data on PD were available in 2021; and (iii) the overdue loans ratio of the economic group was less than 25% of the group's total loan exposure. Whenever the firm was excluded from the analysis for not having data on PD, its loan exposure was considered as part of the economic group's total loan exposure.

loans from being associated with the groups' instrumental corporations that have no operational activity. Thus, financial corporations identified as financial holdings of economic groups with loans in the CCR were considered, in addition to NFCs.

In addition, this exercise used individual financial data from the CBSD's NFCs, PDs of the ICAS, collateral underlying credit agreements recorded in the CCR and LGDs reported by banks in the CCR. GDP at market prices was also used, calculated from the expenditure approach (current prices) of the annual national accounts compiled by Statistics Portugal. The period under review covers the years 2006 to 2020 and all NFCs with data available in the CBSD and ICAS. The selection of the estimation period and the population of firms met a set of criteria that sought to ensure the economic significance of the aggregates or variables considered in the analysis and, in particular, the relevance of the findings for the banking system.

GDP and inflation in NGFS climate scenarios[2] served as a basis for the projections of NFC financial variables, on which climate shocks were applied using other scenario variables. These include aggregate prices and consumptions of various energy sources, GHG emission costs and estimates of damages related to the annual increase in average temperature.[3] The heterogeneity of climate shocks at firm level benefited from granular information produced by data-providing firms. For shocks related to physical risk, Moody's Climate on Demand (COD) database was used,[4] which contains risk scores for a series of climate events. Shocks related to transition risk were calibrated with GHG emission projections produced by Urgentem.[5]

3 Estimation of probability of default (PD)

The projection of NFCs' PDs encompasses two sequential steps. Firstly, historical relationships between one-year PDs and some NFC financial ratios are estimated (estimation stage). Other equations are also estimated for developments in NFCs' assets, revenue and operating costs. Secondly, these accounting variables are projected over a long-term horizon (up to 2050) using previously estimated econometric relationships and NGFS climate scenarios (projection stage). At the same time, a series of shocks is applied. These aim to replicate the materialisation of climate-related physical and transition risks at firm level. Finally, projections of variables make it possible to calculate financial ratios over the same time horizon and consequently, PDs.

[2] The NGFS has disclosed climate scenarios every year since June 2020 (Phase I). The second version of the scenarios, i.e. the one used in this exercise, was published in June 2021 (Phase II). Phase III of the scenarios was disclosed in September 2022.

[3] The NGFS climate transition scenarios used in this exercise were derived by REMIND-MAgPie 2.1-4.2 models. Information on the climate scenarios of Phase II (June 2021) is available on the NGFS scenarios portal (macroeconomic variables and sectoral market variables such as the energy market) and on the Climate Analytics website (geographical information on physical risks by country and region).

[4] Moody's COD is a data platform of the Moody's Analytics group that provides information on physical climate risk on a geographical level. Further details on the company's activities can be found at https://www.moodysanalytics.com/. For further information on the use of these data to analyse risks to financial stability, see Section 2.1.1 of the Annual Report.

[5] Urgentem is a private UK-based firm, part of the ICE group (based in the US), that provides firm-level GHG emissions data and climate risk analytics. Further details on Urgentem's activity can be found at https://www.urgentem.net/. On the types of GHG emissions see footnote 16 in Section 2.1.2 of the Annual Report.

3.1 Estimation stage

In the model adopted, NFCs' one-year PD is assumed to have a logistic specification compatible with its possible domain (between 0 and 1), given by equation PD.1. This specification should better capture the relationship between PD and explanatory variables, especially for firms in the tails of the distribution of economic and financial ratios.[6]

$$PD_{it} = \frac{1}{1 + e^{-x_{it}\beta}} \qquad \text{PD.1}$$

In equation PD.1, PD_{it} corresponds to the one-year probability of default of firm *i* in year *t* estimated by the Banco de Portugal's ICAS model, x_t is the vector of explanatory variables (including the constant and the economic and financial variables of the firm) and β is the vector of the coefficients. To estimate the relationship between the PD and selected explanatory variables, a latent variable is created, the so-called z-score (z_{it}),[7] defined according to equation PD.2.

$$z_{it} = x_{it}\beta = ln\left(\frac{PD_{it}}{1 - PD_{it}}\right) = \alpha + \delta_i + \theta_t + \beta_1 ROA_{it} + \beta_2 Lev_{it} + \varepsilon_{it} \qquad \text{PD.2}$$

In equation PD.2, the dependent variable $z_{it} = x_{it}\beta$ is the term of the logistic function of PD in equation PD.1. Coefficients α, δ_i and θ_t correspond to the constant, the firm fixed effects and the time fixed effects respectively.[8] Variable ROA_{it} refers to the return-on-assets (ROA) ratio and Lev_{it} to the indebtedness ratio, and are calculated according to equations PD.3 and PD.4, where $Rev_{i,t}$, $OpEx_{i,t}$, $TA_{i,t}$ and $FD_{i,t}$ correspond respectively to the revenue, operating costs, total assets and financial debt of firm *i* in year *t*.

$$ROA_{it} = \frac{Rev_{it} - OpEx_{it}}{TA_{it}} \qquad \text{PD.3}$$

$$Lev_{it} = \frac{FD_{it}}{TA_{it}} \qquad \text{PD.4}$$

To capture firm characteristics related to sector of activity and size, the population of firms was divided into ten sub-sets, each corresponding to a size and industry pair (Table 1), in line with the econometric estimation process of Antunes et al. (2016). Thus, equation PD.2 was estimated by ordinary least square (OLS) for each group of firms of size *d* and belonging to industry *r*. [9]

[6] The specification of a logit model corresponds to the approach followed by the SSM in the 2022 climate stress test.

[7] On the z-score, see Antunes, A. et al. (2016), "Firm default probabilities revisited", *Banco de Portugal Economic Studies*.

[8] The Hausman specification test between a fixed effects model and an alternative random effects model resulted in a rejection of the null hypothesis, leading to a preference for fixed effects specification.

[9] The models generating the PDs used in this exercise include many other variables that are not considered here. As the purpose of this work is to project PDs up to 2050, only variables directly related to the main climate impact channels were considered (see Chart I.2.21 in Section 2.2 of the Annual Report).

Table 1 • Models with ICAS organisation

Sector ($r \in \{1, \dots, 5\}$)	Microenterprises ($d = 1$)	SME & Large enterprises ($d = 2$)
Mining and quarrying (B) & manufacturing (C)	(d=1, r=1)	(2, 1)
Construction (F) & Real estate activities (L)	(1, 2)	(2, 2)
Agriculture (A) & Trade (G)	(1, 3)	(2, 3)
Electricity (D) & Sanitation (E) Transports and storage (H)	(1, 4)	(2, 4)
Other	(1, 5)	(2, 5)

Notes: Categories considered in the econometric estimation underlying the Banco de Portugal's Internal Credit Assessment System (ICAS) methodology. The letters in brackets correspond to the sections of the CAE (Portuguese Classification of Economic Activities). In addition, see Antunes et al. (2016).

The same breakdown of the population of NFCs is followed for the equations of total assets, revenue and operating costs.[10] In all three cases, variables are expressed in natural logarithms. In the case of total assets ($lnTA_{i,t}$), the equation shows an autoregressive specification of one period. Equation PD.5 also includes the natural logarithm of nominal GDP ($\ln GDP_t$) and a binary variable identifying the years of decline in real GDP ($dummyRec_t$) as control variables for developments in economic activity, as well as a binary variable identifying the structural break caused by the introduction of the Portuguese accounting standards system in 2010 ($dummySC_t$). The equation considers firm fixed effects.[11]

$$lnTA_{it} = \alpha + \delta_i + \beta_1 lnTA_{i,t-1} + \beta_2 \ln GDP_t + dummyRec_t + dummySC_t + \varepsilon_{it} \quad \text{PD.5}$$

The equations of NFCs' revenue ($lnRev_{i,t}$) and operating costs ($lnOpEx_{i,t}$) also consider an autoregressive component and total assets as regressors. Both equations PD.6 and PD.7 include firm and time fixed effects.

$$lnRev_{it} = \alpha + \delta_i + \theta_t + \beta_1 lnRev_{i,t-1} + \beta_2 lnTA_{it} + \varepsilon_{it} \quad \text{PD.6}$$

$$lnOpEx_{it} = \alpha + \delta_i + \theta_t + \beta_1 lnOpEx_{i,t-1} + \beta_2 lnTA_{it} + \varepsilon_{it} \quad \text{PD.7}$$

The estimated impacts of ROA and indebtedness ratios show the expected signs based on economic intuition: increases in return on assets and indebtedness lower and raise respectively the z-score and consequently the PD of NFCs.

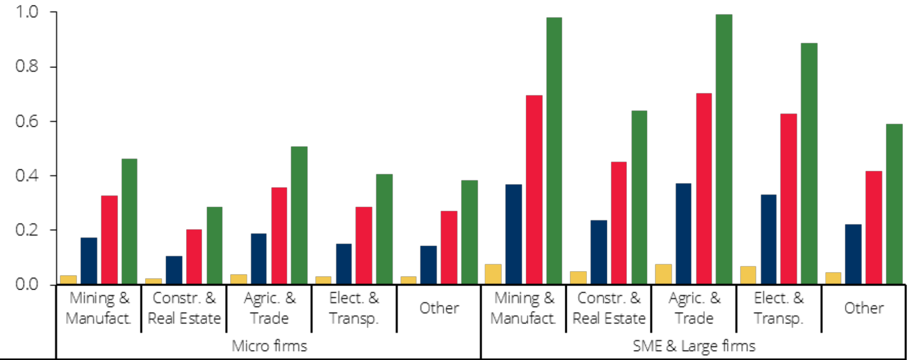
Due to its logistic specification, the higher the initial level of the PD[12] (before the shock on explanatory variables) the higher the PD's sensitivity to changes in financial ratios (Chart 1). In addition, firms in the SME category and large firms, and firms in the manufacturing, trade and agriculture sectors display greater sensitivity of PDs to changes in financial ratios. The estimated coefficients in equations PD.5, PD.6 and PD.7 show the expected signs and magnitudes.

[10] The notation of coefficients in equations (2), (5), (6) and (7) is equal by simplification.

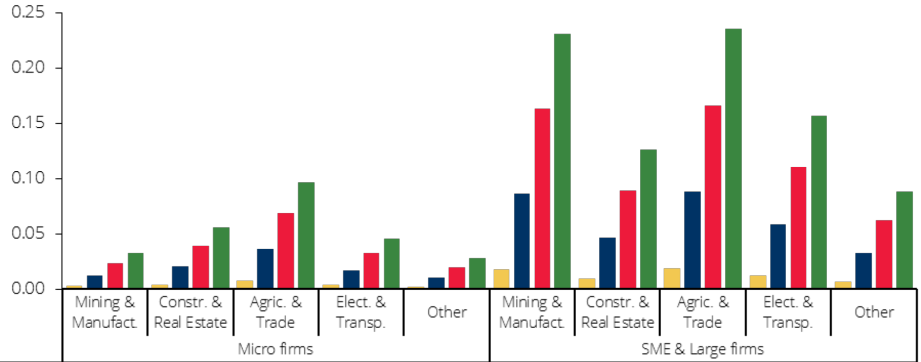
[11] Macroeconomic variables have to be explicitly specified in the model owing to their role in the projection stage. Thus, equation PD.5 does not include time fixed effects as they would be collinear with GDP.

[12] This regularity remains only at the bottom half of the PD domain, i.e. up to a PD of 50%.

Chart 1 • Impacts on the PD of a 1 p.p. decrease in ROA (top panel) and a 1 p.p. increase in the indebtedness ratio (lower panel) | Percentage points



	Micro firms: Mining & Manufact.	Micro firms: Constr. & Real Estate	Micro firms: Agric. & Trade	Micro firms: Elect. & Transp.	Micro firms: Other	SME & Large firms: Mining & Manufact.	SME & Large firms: Constr. & Real Estate	SME & Large firms: Agric. & Trade	SME & Large firms: Elect. & Transp.	SME & Large firms: Other
PD 1%	0.04	0.02	0.04	0.03	0.03	0.08	0.05	0.08	0.07	0.05
PD 5%	0.17	0.11	0.19	0.15	0.14	0.37	0.24	0.37	0.33	0.22
PD 10%	0.33	0.20	0.36	0.29	0.27	0.70	0.45	0.70	0.63	0.42
PD 15%	0.46	0.29	0.51	0.41	0.38	0.98	0.64	0.99	0.89	0.59



	Micro firms: Mining & Manufact.	Micro firms: Constr. & Real Estate	Micro firms: Agric. & Trade	Micro firms: Elect. & Transp.	Micro firms: Other	SME & Large firms: Mining & Manufact.	SME & Large firms: Constr. & Real Estate	SME & Large firms: Agric. & Trade	SME & Large firms: Elect. & Transp.	SME & Large firms: Other
PD 1%	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.02	0.01	0.01
PD 5%	0.01	0.02	0.04	0.02	0.01	0.09	0.05	0.09	0.06	0.03
PD 10%	0.02	0.04	0.07	0.03	0.02	0.16	0.09	0.17	0.11	0.06
PD 15%	0.03	0.06	0.10	0.05	0.03	0.23	0.13	0.23	0.16	0.09

Source: Banco de Portugal. | Notes: The height of each bar corresponds to the difference between the PD after a shock and the level of initial PD (before the shock) in percentage points. The colour of each bar corresponds to the level of the initial PD.

To test the robustness of the results obtained, a model was estimated with observations of all sizes and industries. This joint model consists of equations PD.2, PD.5, PD.6 and PD.7 incorporating binary variables (and interactions with the other regressors) that identify the two dimension groups and five activity sector groups considered. The estimated coefficients are broadly in line with those obtained with the set of models by size-industry described above (Table 2).

Table 2 • Result of estimating the PD equation (impacts on the z-score)

ROA ratio			
Size	Sector	Multiple models	Joint model
1	1	-3.57***	-3.46***
1	2	-2.23***	-2.51***
1	3	-3.93***	-3.98***
1	4	-3.14***	-3.09***
1	5	-2.98***	-2.95***
2	1	-7.50***	-7.01***
2	2	-4.91***	-4.91***
2	3	-7.57***	-7.67*** (a)
2	4	-6.80***	-6.16***
2	5	-4.56***	-4.81***

Indebtedness ratio			
Size	Sector	Multiple models	Joint model
1	1	0.25***	0.25***
1	2	0.44***	0.33***
1	3	0.76***	0.69***
1	4	0.36***	0.32***
1	5	0.22***	0.22***
2	1	1.80***	1.76***
2	2	0.98***	1.09***
2	3	1.83***	2.12*** (a)
2	4	1.22***	1.33***
2	5	0.69***	0.77***

Specific size-sector terms			
Size	Sector	Multiple models	Joint model
1	1	-3.01***	-3.28***
1	2	-3.21***	-3.29*** (a)
1	3	-3.55***	-3.56***
1	4	-2.96***	-2.98***
1	5	-3.40***	-3.23***
2	1	-4.32***	-4.31***
2	2	-3.30***	-3.60*** (a)
2	3	-4.89***	-4.72***
2	4	-4.09***	-4.01*** (a)
2	5	-4.11***	-3.95***

Source: Banco de Portugal. | Notes: The estimated coefficients correspond to the impact on the z-score of a 1-unit change in each independent variable (in the case of dummies, it measures the impact when this feature exists). In multiple models, the specific size-sector terms correspond to the respective model's estimated constant. In the joint model, they correspond to the model's estimated constant plus the estimated coefficients for each size and sector dummy and for the interaction between them (category 1 of each dummy is the basis). The values presented for the other variables correspond to the sum of the coefficients estimated for each of the variables individually and the estimated coefficients for interaction with the size and sector dummies. The robust estimator of the variance-covariance matrix was used. *** $p<0.01$, ** $p<0.05$ and *$p<0.1$. (a) In the joint model, some of the calculated impacts include some coefficient with a p-value higher than 0.001.

3.2 Projection stage (climate shocks)

Using the relationships estimated in the previous stage, it is possible to project the NFCs' accounting variables over the very long-term horizon of the NGFS climate transition scenarios. This stage of the exercise considered the sample of 50 thousand firms detailed in Section 2 Data. For each of these firms, the Banco de Portugal obtained estimates of GHG emissions (scopes 1, 2 and 3) provided by Urgentem.

The z-score and PD projected in the 2021-50 horizon under climate scenario *s* are calculated according to equations PD.8[13] and use projected ROA and indebtedness ratios, $\widehat{ROA}_{it}^{s}$ and $\widehat{Lev}_{it}^{s}$ respectively.

$$\hat{z}_{it}^{s} = \hat{\alpha} + \hat{\delta}_i + \widehat{\beta_1}\widehat{ROA}_{it}^{s} + \widehat{\beta_2}\widehat{Lev}_{it}^{s}$$

$$\widehat{PD}_{it}^{s} = \frac{1}{1 + e^{-\hat{z}_{it}^{s}}} \qquad \text{PD.8}$$

Shocks on the ROA ratio

Projections for the financial variables needed to calculate the ROA ratio use the modified versions of equations PD.5, PD.6 and PD.7, incorporating shocks aiming to replicate the effects of the materialisation of climate-related physical and transition risks.

In the case of total assets, two development paths are projected over the 2021-50 horizon for each scenario *s*: a path that is not affected by climate-related risks, other than those arising from nominal GDP developments in each of the scenarios, and which will be used in the projection of operating costs and as denominator in equations PD.3 and PD.4; another containing the losses associated with the materialisation of physical risks, used in the revenue projection. This solution assumes, on the one hand, that the destruction of physical capital reduces the firm's productive capacity and thus revenue generated, while, on the other hand, (fixed) costs related to the physical assets damaged by the materialisation of physical risks are always incurred by the firm. Thus, projected total assets without and with a physical risk-related shock are given by equations PD.9[14] and PD.10 below, and the shock given by equation PD.11.

$$\widehat{lnTA}_{it}^{s} = \hat{\alpha} + \hat{\delta}_i + \widehat{\beta_1}\widehat{lnTA}_{i,t-1}^{s} + \widehat{\beta_2}lnGDP_t^{s} \qquad \text{PD.9}$$

$$T\widehat{ADmg}_{it}^{s} = \widehat{TA}_{it}^{s} + STA_{it}^{s} \qquad \text{PD.10}$$

$$STA_{it}^{s} = CFR_{it}^{s} \times AFR_{it}^{s} \times PhC_{it}^{s}, where\ STA_{it}^{s} \leq 0 \qquad \text{PD.11}$$

In equation PD.11, shock $\boldsymbol{STA_{it}^{s}}$ corresponds to the impact of physical risk on scenario *s* for firm *i* in projection year *t*. This shock is composed of a term related to chronic physical risk ($\boldsymbol{CFR_{it}^{s}}$), i.e. to the economic impacts of long-term changes in climate patterns, and a term that seeks to capture the impacts of extreme weather events, the so-called acute physical risks ($\boldsymbol{AFR_{it}^{s}}$). In addition, these

[13] By definition, the period fixed effect varies historically and its value for the projection years is unknown. With its average in the estimation period being close to zero, it has been assumed that $\hat{\theta}_t = 0,\ para\ t \in [2021; 2050]$.

[14] Nominal GDP (current prices) for each climate transition scenario is not available on the NGFS scenarios portal directly at level, but rather at deviations from real GDP (2016 prices) of a baseline scenario, i.e. in a world with no climate change. Nominal GDP was calculated using these and other variables available in the scenarios, such as inflation in the baseline scenario and its deviations, in each scenario.

terms are multiplied by the physical capital[15] of each NFC, PhC_{it}^{s}, leading to the estimate of the physical risk shock in euro.

In the case of chronic physical risk, the average impact on NFCs is captured by the ratio Dmg_t^s/PhC_t^s (Chart 2) multiplied by the deviations in projections for the temperature of the district of the head office of firm *i* from the national average in 2020 (normalised to 1) in each scenario (Chart 3) – equation PD.12. The variable Dmg_t^s corresponds to annual losses in terms of economic activity in Portugal in each scenario.[16] This variable mainly reflects declines in productivity (labour, land and capital) related to the increase in the global mean temperature, and thus, being an aggregate estimate for total economy, it is scaled by the aggregate physical capital of all NFCs. Normalised temperature deviations seek to capture the geographical heterogeneity of the effects of global warming.

$$CFR_{it}^{s} = \frac{Dmg_t^s}{PhC_t^s} \times \left(1 + \frac{Temp_{it}^{s} - \overline{Temp}_{2020}^{s}}{\overline{Temp}_{2020}^{s}}\right) \qquad \text{PD.12}$$

Acute physical risks are modelled using scores calculated by Moody's COD, which translate the long-term risk level associated with extreme weather events according to geographical location. Three physical risk events are considered in this exercise (floods, wildfires and sea level rise),[17] and a deviation from the national average (normalised to 1) is calculated for each of them. The acute physical risk component corresponds to the product of normalised deviations of each extreme event, with a required minimum threshold of 1 for the deviation of each event, i.e. at the national average level, as per equation PD.13. This prevents lower and higher-than-average deviations associated to different events from being mutually offsetting. Thus, the effects of this channel are concentrated on NFCs with higher physical risk.

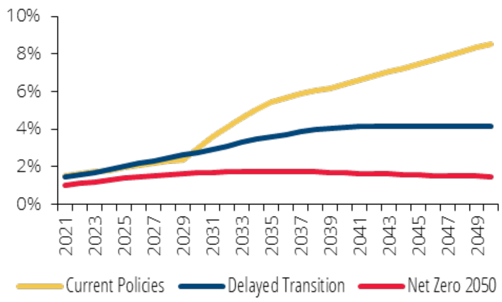
$$AFR_{it}^{s} = \prod_{h}^{H} \max\left\{1;\ \frac{score_{it}^{h}}{\overline{score}_{t}^{h}}\right\} \qquad \text{PD.13}$$

[15] Corresponds to the aggregate of tangible fixed assets and biological assets of all NFCs. For each individual firm, physical capital was considered to grow in each scenario at the growth rate of projected (undamaged) total assets.

[16] Economic activity losses were estimated by damage functions calibrated by the consortium that produced the NGFS scenarios using the temperature levels inferred from the GHG emissions paths projected in each scenario. This exercise considered damages calculated with the 95th percentile for the Current Policies scenario, the median in the Delayed Transition scenario, and the 5th percentile in the Net Zero scenario. For further information on the calibration of damage functions, see the technical documentation of NGFS scenarios and Kalkuhl & Wenz (2020).

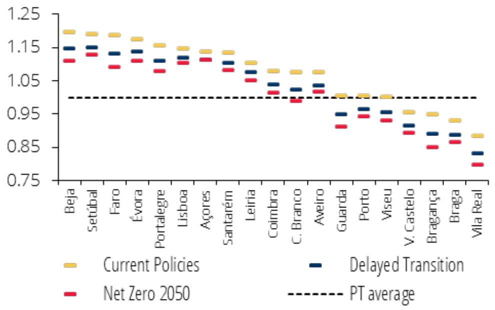
[17] The risk of sea level rise is indeed a chronic physical risk, as its effects are observed gradually over time. This risk could therefore be included in equation PD.12 and excluded from equation PD.13. However, to simplify the equations presented, all the information on physical risks from Moody's COD scores was included in equation PD.13. Note that in equation PD.11 the solution is neutral from an algebraic viewpoint.

Chart 2 • Projected GDP losses
| As a percentage of physical capital



Sources: NGFS and Banco de Portugal calculations. | Notes: Up to 2029 the Current Policies and Delayed Transition scenarios considered damages calculated with the median of the global mean temperature (GMT) path up to the end of the century; from 2030 onwards the Current Policies scenario considered the 95th percentile, keeping the median in the Delayed Transition scenario; the Net Zero 2050 scenario considered the 5th percentile. For further details on damage functions, please refer to the NGFS methodological document on scenarios, available on the NGFS scenarios portal.

Chart 3 • Temperature deviations from the national average in 2020, by district, projection in 2050



Sources: Climate Analytics and Banco de Portugal calculations. | Notes: Data for the Autonomous Region of Madeira are not available, and therefore data for the Autonomous Region of the Azores were applied to both autonomous regions. National average in 2020 was normalised to 1. The Net Zero 2050 scenario considered the 2.5th percentile of the projected temperature distribution in each district; the Delayed Transition scenario considered the median; the Current Policies scenario considered the 97.5th percentile.

Equation PD.14 of NFC revenue over the projection period incorporates, in addition to the damaged assets calculated in equation PD.10, a shock related to transition risk, which aims to capture the decline in demand associated with goods or services with higher GHG emissions at the time of their consumption or use. The shock results from multiplying an adjusted indirect tax rate ($AdjVAT_{it}^{s}$) by a semi-elasticity (θ_{ECB}) estimated according to Alogoskoufis et al. (2021) in a model similar to equation PD.14 .

$$\widehat{lnRev}_{it}^{s} = \hat{\alpha} + \hat{\delta}_i + \hat{\beta}_1 \widehat{lnRev}_{i,t-1}^{s} + \hat{\beta}_2 ln\widehat{TADmg}_{it}^{s} + \theta_{ECB} \times AdjVAT_{it}^{s} \qquad \text{PD.14}$$

In this exercise, the adjusted indirect tax rate corresponds to the average VAT rate in Portugal in 2021 (as a percentage), plus a surcharge that increases over the projection horizon, with different profiles depending on the scenario. Surcharges to the average VAT rate are set according to each NFC's carbon intensity in 2020, as measured by scope 3 GHG emissions, in the 'use of sold products' category, in relation to revenue in that year. The surcharge increases linearly throughout the distribution (by decile) of carbon intensity up to the maximum arbitrarily set for a given year and scenario (Table 3). Thus, the first decile of carbon intensity distribution (NFCs with lower carbon intensity) has an additional 0 p.p. over the entire horizon and the tenth decile (NFCs with higher carbon intensity) an additional 3 p.p. in 2035 in the Delayed Transition scenario and an additional 2 p.p. in 2030 in the Net Zero 2050 scenario. For the Current Policies scenario every year and for the Delayed Transition scenario up to 2029, the surcharge was considered to be 0 p.p. for any level of carbon intensity, resulting from the absence of climate transition. Finally, to reflect the progress of transition over the projection horizon and its maturity after a few years, the shock is expected to peak and gradually unwind after that moment.

Table 3 • Surcharge to the VAT rate in the demand shock (transition risk) | Per cent

Scenario	Year	Decile 2	Decile 4	Decile 6	Decile 8	Decile 10
Delayed Transition	2025	0.00	0.00	0.00	0.00	0.00
	2030	0.22	0.67	1.11	1.56	2.00
	2035	0.33	1.00	1.67	2.33	3.00
	2040	0.22	0.67	1.11	1.56	2.00
	2045	0.11	0.33	0.56	0.78	1.00
	2050	0.00	0.00	0.00	0.00	0.00
Net Zero 2050	2025	0.11	0.33	0.56	0.78	1.00
	2030	0.22	0.67	1.11	1.56	2.00
	2035	0.11	0.33	0.56	0.78	1.00
	2040	0.00	0.00	0.00	0.00	0.00
	2045	0.00	0.00	0.00	0.00	0.00
	2050	0.00	0.00	0.00	0.00	0.00

Source: Banco de Portugal calculations. | Notes: For the Current Policies scenario, the surcharge is calibrated to 0% over the whole projection horizon. Grey cells correspond to the maximum shocks arbitrarily set for NFCs in decile 10 of carbon intensity.

The projection of NFCs' operating costs is complemented with two shocks related to transition risks and one to physical risk. Shocks on operating costs are added linearly to the projections of operating costs in euro and are set out in changes vis-à-vis 2021, as illustrated by equations PD.15.

$$\widehat{lnOpEx}_{it}^{s} = \hat{\alpha} + \hat{\delta}_i + \widehat{lnOpEx}_{i,t-1}^{s} + \beta_2 \widehat{lnTA}_{it}^{s}$$

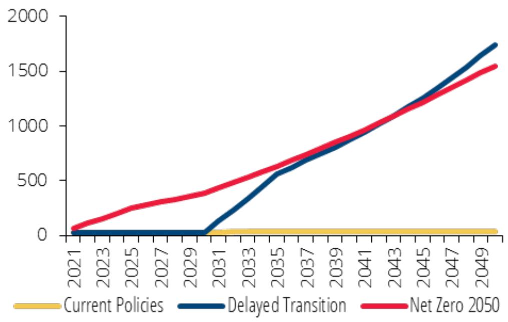
$$\widehat{OpEx}_{it}^{s} = e^{\widehat{lnOpEx}_{it}^{s}} + \Delta CarbonCost_{it}^{s} + \Delta EnergyCost_{it}^{s} + \Delta InsuranceCost_{it}^{s} \qquad \text{PD.15}$$

In equation PD.16, $\boldsymbol{\Delta CarbonCost_{it}^{s}}$ corresponds to the annual increase in costs related to GHG emissions (transition risk) and depends in each scenario on the price ($\boldsymbol{PCarbon_{t}^{s}}$) per tonne of CO2 equivalent (tCO2e) and scope 1 emissions of each NFC ($\boldsymbol{Scope1_{it}^{s}}$). In the Current Policies scenario the carbon price remains stable, illustrating the absence of climate policies to reduce GHG emissions (Chart 4). On the contrary, in the Net Zero 2050 scenario the carbon price increases consistently up to 2050, imposing an increasingly higher cost on direct GHG emissions and providing an incentive to their reduction. The carbon price only increases from 2030 onwards in the Delayed Transition scenario and evolves at a higher pace than in the Net Zero 2050 scenario, reflecting the more urgent nature of the transition, given its later start.

$$\Delta CarbonCost_{it}^{s} = PCarbon_{t}^{s} \times Scope1_{it}^{s} - PCarbon_{2021}^{s} \times Scope1_{i,2021}^{s} \qquad \text{PD.16}$$

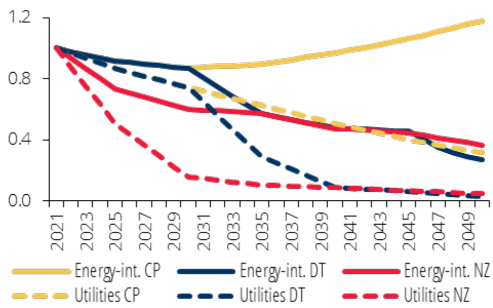
Scope 1 emissions of NFCs decrease in all scenarios and sectors, albeit at different paces. In the Current Policies scenario, emissions decrease at a slow pace, only reflecting current climate policies, insufficient to achieve the goals of the Paris Agreement. In the case of Net Zero 2050 and Delayed Transition, emissions decline more sharply in order to achieve the targets for limiting the global mean temperature to levels well below 2°C above pre-industrial levels. However, the emission reduction profile differs depending on the sector, resulting in differentiated sectoral impacts with the introduction of this cost (Chart 5).

Chart 4 • Carbon price | Euro per tCO2e



Sources: NGFS and Banco de Portugal calculations.

Chart 5 • Scope 1 GHG emissions | Index (2021=1)



Sources: Urgentem and Banco de Portugal calculations. | Notes: Scope 1 emissions correspond to NFCs' direct GHG emissions (footnote 16 in Section 2.1.2 of the report). CP – Current Policies; DT – Delayed Transition; NZ – Net Zero 2050.

The second shock of transition risks on operating costs seeks to simulate changes in energy costs in each transition scenario. In equation PD.17 the increase in the energy cost ($\Delta EnergyCost_{it}^{s}$) for firm *i* is a function of prices ($PEnergy_{et}^{s}$), in euro per gigajoule (GJ), and of consumptions ($ConsEnergy_{eit}^{s}$) in GJ of each form of energy *e*.

$$\Delta EnergyCost_{it}^{s} = \sum_{e}(PEnergy_{et}^{s} \times ConsEnergy_{eit}^{s}) - \sum_{e}\left(PEnergy_{e,2021}^{s} \times ConsEnergy_{ei,2021}^{s}\right) \qquad \text{PD.17}$$

Energy consumption per NFC is not available in the databases used, but can be estimated using each firm's GHG emissions provided by Urgentem. There are two types of GHG emissions generated by the firm's energy consumption: one of a direct nature (scope 1 emissions), arising from the combustion of energy sources in the facilities or equipment controlled by the company itself; the other of an indirect nature (scope 2 emissions), which corresponds to emissions produced by electricity and heat[18] acquired from third parties. Thus, the estimation of energy consumption per firm was twofold: Fuels, using scope 1 GHG emissions; and Electricity, on the back of scope 2 emissions. For the price of Electricity the variable available in the NGFS scenarios was used. For Fuels, an average of fuel prices considered in this exercise was used.

Equations PD.18 illustrate the algebraic mechanics of the estimation process of energy consumption, where $Scope1_{it}^{s}$ and $Scope2_{it}^{s}$ represent scope 1 and 2 emissions of each NFC *i* in each year *t* of scenario *s*; $w_{F,pit}^{s}$ and $w_{E,pt}^{s}$ are the share of each primary energy[19] *p* in total polluting primary energy (i.e. excluding renewables) respectively in the production of Fuels (*F*) and Electricity (*E*); $wb_{F,it}^{s}$ and $wb_{E,t}^{s}$ are the shares of polluting primary energy sources in total consumption of primary sources (i.e. including renewables) respectively for the production of Fuels and Electricity; and CI_{p}^{F} and CI_{p}^{E} are the average carbon content[20] of each primary source *p* used in the production of fuels and electricity respectively.

[18] To simplify, from this point onwards 'electricity and heat' will be referred to only as 'Electricity'.

[19] Primary energy corresponds to energy sources found directly in nature (e.g. oil, natural gas, solar energy, etc.).

[20] The carbon content of a fuel corresponds to the amount of greenhouse gases expressed in tCO_2e released by the combustion of a particular amount of this fuel. The carbon content used in this exercise corresponds to an average of the coefficients published by the IPCC (*2006 IPCC Guidelines for National Greenhouse Gas Inventories*), weighted by the consumptions observed in 2020 of each primary energy source in Portugal.

$$ConsEnergy_{C,it}^{s} = \frac{1}{wb_{F,it}^{s}} \times \sum_{p} \frac{Scope1_{it}^{s} \times w_{F,pit}^{s}}{CI_{p}^{F}}$$

$$ConsEnergy_{E,it}^{s} = \frac{1}{wb_{E,t}^{s}} \times \sum_{p} \frac{Scope2_{it}^{s} \times w_{E,pt}^{s}}{CI_{p}^{E}}, \qquad \text{PD.18}$$

$$p \in \{coal, oil, gas, biomass\}$$

Consumption was estimated through equations PD.18 in two steps: the first consisted of projecting up to 2050 the energy mix for Fuels and Electricity in each scenario, i.e. shares $\boldsymbol{w_{F,pit}^{s}}$, $\boldsymbol{w_{E,pt}^{s}}$, $\boldsymbol{wb_{F,it}^{s}}$ and $\boldsymbol{wb_{E,t}^{s}}$; the second step corresponds to the estimation of consumption, according to the shares estimated in the first step, using equation PD.18.

The energy mix corresponds to the amounts of energy consumed, by primary source, to produce another form of energy (secondary energy).[21] The form of energy referred to as Fuels is a highly heterogeneous aggregate, and therefore its composition by industry is also very diverse. Thus, the energy mix used in fuel production was projected with some sectoral breakdown, i.e. shares $\boldsymbol{w_{F,pit}^{s}}$ and $\boldsymbol{wb_{F,it}^{s}}$ are specific to the industry to which firm *i* belongs.

To operationalise this first step, Portugal's energy balance in 2020 was obtained from Eurostat, containing the quantities (in kilotonnes of oil equivalent) of each primary energy source consumed, on the one hand, to produce Electricity and on the other, for transformation into other forms of energy, i.e. to produce Fuels. Primary energy sources were grouped into categories corresponding to the primary energy consumption variables available in the NGFS scenarios (Table 4) and considered relevant to the Portuguese case (coal, oil, natural gas, biomass and other renewables).[22] The paths of these variables were used to project up to 2050 the consumption of each primary energy source used for the production of Electricity and Fuels, based on the quantities of each primary energy source consumed in 2020. In addition, in the case of Fuels, the mix of primary sources used to produce final energy[23] (except for electricity) consumed by each industry was projected.[24] Thus, while for Electricity the energy mix is the same for all firms, for Fuels it varies according to industry.

[21] Secondary energy refers to forms of energy not found directly in nature (e.g. electricity, refined fuels), i.e. produced with recourse to primary energy.

[22] Given that some variables for Portugal were not available in the NGFS scenarios, projections for the European Union were used. For some primary energies, in addition to total consumption, there is consumption for electricity production purposes, and therefore the consumption of primary energies for fuel production was calculated by the difference between total consumption of that primary source and consumption for electricity production.

[23] Energy available for consumption by the final consumer, after use by the energy sector.

[24] Energy balances compiled by Eurostat divide final energy consumption into 25 sectors, of which 13 are industrial sectors, six transports, one the energy sector and five other sectors (including trade, services and activities of households). For further details, see Eurostat's methodological documentation.

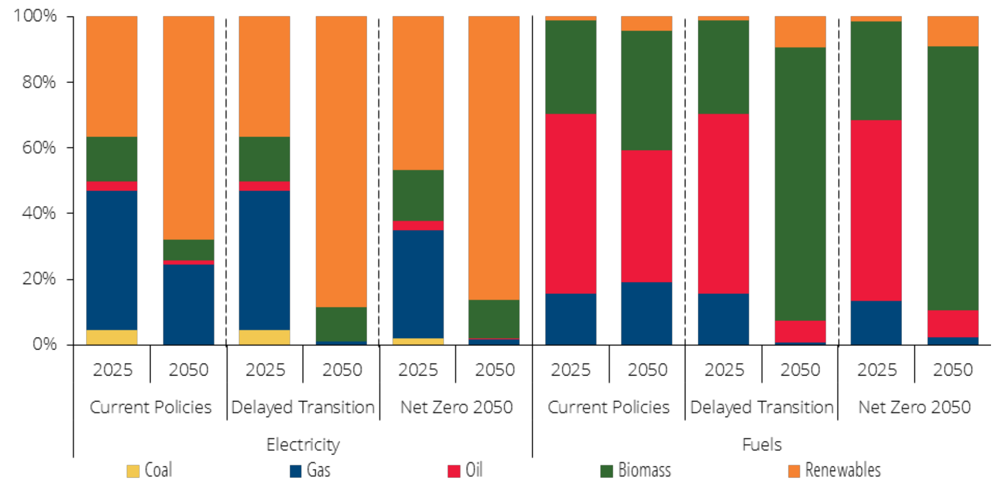
Table 4 • Stylised energy balance

			Inputs (sources)					
			Coal	Oil	Gas	Biomass	Renewables	Electricity
Outputs (uses)	Primary energy	Primary production	Production of primary energies (e.g. extraction of fossil fuels)					
		Other changes	Other changes in primary energies (e.g. imports and exports)					
	Secondary energy	Electricity production	Quantities of energy for computing the **electricity** production mix					
		Fuel production						
	Final energy	Final energy consumption						
		Sector A	Quantities of energy for computing the production mix of **fuels** consumed by **sector A**					
		Sector Z	Quantities of energy for computing the production mix of **fuels** consumed by **sector Z**					

Notes: Inputs refer to primary energy sources and to electricity and heat consumed. Outputs refer to the uses of primary energies for the production of other forms of energy and for final consumption. The various detailed primary energy sources (inputs) of Eurostat's energy balance were grouped into categories corresponding to primary energies available in the NGFS scenarios, with the exception of electricity, for which there is no primary production by definition.

In the Current Policies scenario, fossil fuels continue to play a relevant role in the energy mix of Electricity and Fuels (natural gas and oil) at the end of the projection horizon (Chart 6). In turn, in the scenarios where energy transition occurs, renewable sources play a leading role in the production of Electricity, and biomass in the production of Fuels (biofuels), leading to a greater reduction in GHG emissions.

Chart 6 • Primary energy mix | Per cent



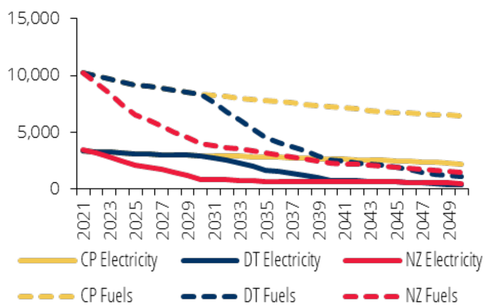
Sources: NGFS, Eurostat and Banco de Portugal calculations. | Notes: The Fuels mix corresponds to a weighted average of the industries.

In the second step, scope 2 emissions of each NFC were broken down into the four polluting primary sources (coal, natural gas, oil and biomass), using the projected Electricity mix, and dividing each part by the average carbon content of each primary source, so as to obtain estimates of Electricity consumption by primary source. To account for Electricity consumption from renewable sources, the sum of these estimates was divided by the proportion of polluting energy. The consumption of Fuels was carried out in the same way but using scope 1 emissions and the energy mix corresponding to the industry to which the NFC belongs.

Estimated consumptions at aggregate level follow a downward trend in all scenarios. In line with the narrative of the scenarios, the downward trend starts earlier in the Net Zero 2050 scenario and later and more abruptly in the Delayed Transition scenario (Chart 7).

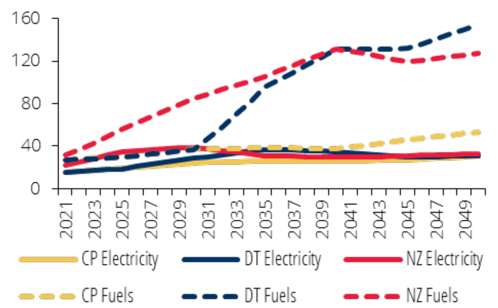
Fuel prices, dominated by non-renewable sources (mainly oil), increase significantly in the Delayed Transition and Net Zero 2050 scenarios, reflecting the higher costs (taxes on GHG emissions) associated with their use (Chart 8). By comparison, electricity prices show a more stable behaviour, although also increasing during the period when transition is more intense, returning to figures close to the current ones in 2050.

Chart 7 • Estimated energy consumptions | In TJ



Sources: Urgentem, NGFS, Eurostat and Banco de Portugal calculations. | Notes: 1 terajoule (TJ) – 1,00 gigajoules (GJ). CP – Current Policies; DT – Delayed Transition; NZ – Net Zero 2050.

Chart 8 • Energy prices | Euro per GJ



Sources: NGFS and Banco de Portugal calculations. | Notes: The fuel price in the various scenarios corresponds to an average of the secondary or primary energy prices (as available) weighted by their share in the energy mix of fuels other than electricity. CP – Current Policies; DT – Delayed Transition; NZ – Net Zero 2050.

In turn, the physical risk-related shock on operating costs is calculated according to equation PD.19 and models the increase in firms' insurance premia that cover the risks of destruction of their assets due to extreme weather events. This shock corresponds to the increase in the actuarially fair price of insurance covering damages to physical assets and may also capture the increase in health insurance costs for employees or even the higher operating risk associated with greater thermal discomfort.

$$\Delta InsuranceCost_{it}^{s} = InsuranceCost_{it}^{s} - InsuranceCost_{i,2021}^{s} \qquad \text{PD.19}$$

The term $InsuranceCost_{it}^{s}$ is constructed similarly to the asset shock computed with equation PD.11, but with the multiplication factor I_{t}^{s} corresponding to the fraction of insured assets in each year for a given scenario — equation PD.20.

$$InsuranceCost_{it}^{s} = CFR_{it}^{s} \times AFR_{it}^{s} \times I_{t}^{s} \times PhC_{it}^{s} \qquad \text{PD.20}$$

The factor I_{t}^{s} in 2021 was defined as the proportion of economic losses caused by weather and climate-related extreme events covered by insurance, based on historical information for the period between 1980 and 2020 in European Economic Area countries.[25] The figure for Portugal, well below the European Union average, should adopt a convergence path towards this target by 2050. However, to reflect the higher incidence of physical risks in the Current Policies and Delayed Transition scenarios, and the resulting higher need to cover assets, from 2030 onwards the evolution of the fraction of insured assets in these two scenarios differs from that projected for the Net Zero 2050 scenario (Chart 9). Thus, from 2030 onwards, the share of insured assets adopts a converging path towards the maximum level among European countries (Denmark) in the Current Policies scenario and towards the 75th percentile of all European countries (Switzerland) in the Delayed Transition scenario.

Indebtedness ratio shocks

The projection of the indebtedness ratio with climate shocks follows a simpler methodology than in the case of ROA, given that no equation for financial debt developments was specified. For this variable, a change at the same growth rate estimated for total non-damaged assets (denominator) was assumed. Thus, before shocks are applied, the indebtedness ratio of each firm remains constant throughout the projection horizon.

In this exercise one shock related to transition risk and another related to physical risk were calibrated. The indebtedness ratio incorporating both shocks is calculated according to equation PD.21.

$$\widehat{Lev}_{it}^{s} = \frac{\widehat{FD}_{it}^{s} + Investment_{it}^{s} + UninsuredDamage_{it}^{s}}{\widehat{TA}_{it}^{s}} \qquad \text{PD.21}$$

The first shock ($\boldsymbol{Investment_{it}^{s}}$) consists of an increase in investment in the replacement of productive technology as a result of a need to reduce GHG emissions (PD.22), assuming that this investment is fully financed by the increase in NFC financial debt. The financial debt is expected to increase in proportion to the annual decrease in total GHG emissions of each NFC ($\boldsymbol{\Delta GHG_{it}^{s}}$). For 2021 and 2022 the average replacement cost ($\boldsymbol{ReplacementCost_{t}^{s}}$) was calibrated on the basis of the costs of new energy production facilities ($\boldsymbol{Cost_{kt}}$), for each technology *k*, estimated by Gillingham and Stock (2018)[26] and the share of each of these technologies in the production of electricity ($\boldsymbol{w_{kt}^{s}}$), given by the NGFS scenarios. For the following years, the average path of these technologies' costs in the NGFS scenarios ($\boldsymbol{cc\_arc_{t}^{s}}$) was used to project $\boldsymbol{ReplacementCost_{t}^{s}}$ in the remainder of the horizon, using the same shares $\boldsymbol{w_{kt}^{s}}$.

$$Investment_{it}^{s} = \Delta GHG_{it}^{s} \times ReplacementCost_{t}^{s} \qquad \text{PD.22}$$

$$\begin{aligned} ReplacementCost_{t}^{s} &= \sum\nolimits_{k} Cost_{kt} \times w_{kt}^{s} \;\; se\ t \le 2022 \\ ReplacementCost_{t}^{s} &= ReplacementCost_{t-1}^{s} \times (1 + cc\_arc_{t}^{s}) \;\; se\ t > 2022 \end{aligned} \qquad \text{PD.23}$$

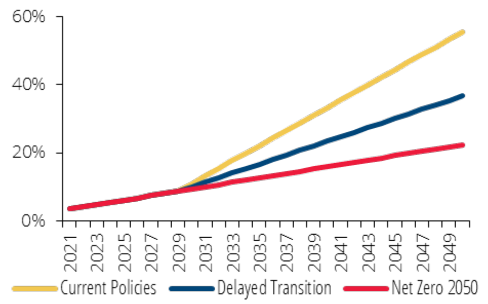
As expected, in the Current Policies scenario and the early years of the Delayed Transition scenario the average replacement cost is residual, due to a small decrease in GHG emissions (Chart 10).

[25] Database available on the European Environment Agency's website.

[26] The technologies considered were as follows: coal plants with carbon capture and storage technologies (CCS); natural gas plants with CCS; conventional natural gas plants; photovoltaic plants; concentrated solar power plants (CSP).

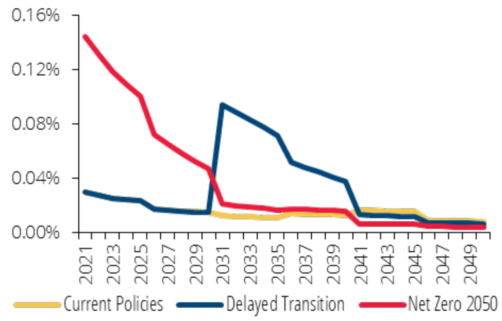
This shock is more significant in the most intense stages of climate transition in the Net Zero 2050 and Delayed Transition scenarios.

Chart 9 • Fraction of insured assets
| Per cent



Sources: European Environment Agency and Banco de Portugal calculations. | Notes: This figure was calibrated to converge, from 2030 onwards, with maximum coverage, the 75th percentile, and the EU average observed in 2021 for the Current Policies, Delayed Transition and Net Zero 2050 scenarios respectively. Between 2021 and 2029, the path is consistent with convergence by 2050 with the EU average and is the same for all scenarios.

Chart 10 • Average replacement cost
| As a percentage of assets



Sources: NGFS and Banco de Portugal calculations. | Note: 2021 and 2022 costs are calibrated according to Gillingham and Stock (2018).

The shock related to physical risk ($UninsuredDamage_{it}^{s}$) is calculated similarly to equation PD.18, but replacing I_t^s with $1 - I_t^s$, i.e. the fraction of assets that are not covered by insurance and are, as such, borne directly by firms. Thus, rebuilding the capital damaged by the materialisation of physical risks implies increasing NFC financial debt to the same amount of damaged but uninsured assets – equation PD.24.

$$UninsuredDamage_{it}^{s} = CFR_{it}^{s} \times AFR_{it}^{s} \times (1 - I_t^s) \times PhC_{it}^{s} \qquad \text{PD.24}$$

4 Estimation of loss given default (LGD)

Climate change due to global warming is linked to a more frequent and more intense materialisation of physical risks, with a potential impact on the value of loan collateral. The NGFS scenarios incorporate an estimate of the materialisation of chronic physical risks, i.e. the impact of an increase in average temperature on economic activity between 2020 and 2050. Rising temperatures translate into a decline in economic activity and a more accelerated deterioration of physical assets, which weigh on GDP developments and asset valuation in the economy. The increased deterioration of physical assets and their potential devaluation are reflected in the value of loan collateral, contributing to an increase in the expected losses of financial institutions.

A more frequent and more intense materialisation of acute climate events, such as wildfires or floods, could also lower the value of loan collateral. In addition to information on chronic physical risks embedded in the NGFS scenarios, asset exposure to the materialisation of acute physical risks has been considered, depending on the geographical location of the firms' head offices.

The impact of a potential materialisation of (chronic and acute) physical risks is incorporated in the LGD projection of loans to NFCs through a projection of the value of collateral identified in the CCR for each loan. The value of collateral projected over the 2020-50 horizon is then considered in combination with lender and loan agreement characteristics generating LGD estimates for the evaluation horizon. This section sequentially describes the LGD estimation methodology considered in this projection exercise.

4.1 LGD definition and collateral identification

The starting point for the LGD calculation in the different scenarios is the share of uncollateralised outstanding amount, referred to as *naive LGD*, represented in expression LGD.1. The ratio of the collateral value to the outstanding amount, here referred to as V/M ratio, will be instrumental in projecting the collateral value in the climate scenarios and estimating the collateral recovery rate by financial institutions.

$$LGD_{naive} = max\left\{0; 1 - \frac{Total\ collateral}{Total\ loans\ outstanding}\right\}$$

where LGD.1

$$\frac{V}{M} \equiv \frac{Total\ collateral}{Total\ loans\ outstanding}$$

As part of the LGD estimate, information from different collateral types identified in the CCR was considered for each loan with reference to December 2019. This reference date was selected to avoid considering the increase in State-guaranteed loans resulting from support measures for firms to mitigate the effects of the COVID-19 pandemic.

The various types of collateral include collateral that may undergo damage from the materialisation of physical risks and collateral whose value may vary due to the materialisation of transition risks. As in the ECB's stress test exercise by Alogoskoufis et al. (2021), collateral exposed to physical damage, e.g. commercial or residential real estate, was considered. In addition, developments in the value of collateral in the form of financial assets were dependent on climate scenarios.

The total value of collateral underlying each loan *c* is the sum of physical and non-physical collateral (LGD. 2), which is categorised in one way or another depending on whether it is exposed to physical deterioration by climate events. Table 5 details the allocation of the various categories of collateral in the CCR to these two categories. The physical collateral category includes commercial real estate, residential real estate and other physical goods. The non-physical collateral category includes public sector guarantees, cash and deposits, shares, and trade receivables. Collateral/guarantees were excluded if categorised as Personal guarantees or Other protection, given the high uncertainty surrounding the value of this collateral/these guarantees.

$$Total\ collateral = Physical\ collateral + Non\text{–}\ physical\ collateral \qquad \text{LGD.2}$$

Physical collateral corresponds to approximately 83% of total collateral considered in this exercise. Commercial real estate, other physical collateral and other real estate are the most relevant categories in total physical collateral. In turn, shares and public sector guarantees are the collateral with the highest amount in non-physical collateral. Collateral is assumed to remain available until the end of the simulation horizon, irrespective of the loan maturity, and there are no replenishments in collateral in the event of devaluation.

Table 5 • Categorisation of information on collateral in the CCR by type of physical or non-physical collateral

Type of collateral/guarantee	Share (Dec. 19)	Physical/ Non-physical
Cash and deposits or similar	2.5	Non-physical collateral
Listed/unlisted debt securities, loans and life insurance policies	0.6	
Shares and other equity – listed	3.5	
Shares and other equity – unlisted	2.0	
Financial guarantees other than credit derivatives	6.5	
Trade receivables	1.0	
Commercial real estate – residential	0.6	Physical collateral
Commercial real estate – retail	4.0	
Commercial real estate – offices	11.3	
Commercial real estate – industrial	4.7	
Commercial real estate – other	6.2	
Real estate under construction for commercial purposes	2.1	
Residential real estate	9.7	
Other real estate	25.6	
Other physical collateral	19.8	

Source: Banco de Portugal. | Notes: The categories shown refer to the protection categories considered in the CCR. The Personal guarantees and Other protection categories were not considered in the analysis and correspond to approximately 70% of total protection in the CCR. Collateral in these categories was considered when identified as having the characteristics of State-guaranteed lines (SGLs), i.e. when granted by entities identified as mutual guarantee companies or provided by the general government institutional sector. The amount identified under this criterion corresponds to 0.2% of the total amount of collateral as at December 2019 or 15.1% of the total amount of SGLs considered in this exercise.

4.2 Developments in the V/M ratio

In the absence of climate shocks and deterioration resulting from physical risks, the value of the V/M ratio was considered to remain constant over the projection horizon. This assumption disregards potential time dynamics associated with the gradual repayment of the loan until maturity or the normal deterioration of goods as a result of operating activity. Thus, in line with the static balance sheet assumption, the value of collateral is assumed to grow at the same pace as corporate debt, as considered when modelling default probabilities (Section 3).

Two transmission channels of climate scenarios were considered in the V/M ratio: (i) the effects of the macroeconomic scenario on the value of collateral and (ii) physical losses stemming from the materialisation of shocks from chronic and acute physical risks. The three NGFS scenarios – Net Zero 2050, Delayed Transition and Current Policies – include variables used to determine developments in the value of some of the assets considered as collateral. The update factors stem directly from the economic developments estimated for each scenario (e.g. GDP) or from the expected impact of each scenario on equilibrium asset values (e.g. the house price index). In turn, physical losses reflect the total deterioration of physical assets in the economy according to the evolution in temperature in each scenario, as well as the potential materialisation of extreme weather events and related destruction of value.

Given that the V/M ratio is assumed to remain constant over the projection horizon, it is affected independently by each of the climate transmission channels. For each projection year, the V/M ratio is multiplied by the rate of change in the collateral update factor and by the deterioration rate associated with the impact of the temperature increase, weighted by the share of each collateral category in the total amount of collateral in a loan, as described in equation LGD.3.

$$\frac{V^s}{M_{lt}} = \frac{V}{M_{l,2020}} \times \sum_g \left[w_g \times \left(1 + NGFS^s_{\mathrm{lg}\,(t,2020)}\right) \times \left(1 + Loss\ rate^s_{lg(t,2020)}\right)\right] \qquad \text{LGD.3}$$

In this equation, $\frac{V^s}{M_{l,t}}$ corresponds to the V/M ratio of loan *l* in estimate year *t* in each NGFS scenario *s* and $\frac{V}{M_{l,2020}}$ corresponds to the loan's V/M ratio at the starting point.[27] The term $NGFS^s_{\mathrm{lg}\,(t,2020)}$ corresponds to the update factor between the start of the projection (2020) and estimate year *t* for collateral type *g* of loan *l* in scenario *s*. In turn, $\boldsymbol{Loss\ rate^s_{lg(t,2020)}}$ corresponds to the physical loss rate of physical collateral *g* between the start and estimate year *t* of loan *l* in scenario *s*. The collateral's physical loss rate is zero when the collateral considered is not physical. Finally, $\boldsymbol{w_g}$ corresponds to the share of collateral type *g* in the total collateral amount of loan *l*.

Each climate scenario includes an update factor for the value of different assets. For the collateral pool for which there is an appropriate update factor, the change in the value of collateral corresponds to the difference in value between the Current Policies and Delayed Transition scenarios and the Net Zero 2050 scenario. This option limits the valuation of assets to the difference relative to the Net Zero 2050 scenario, disregarding the growth assessed in this scenario. As this is the most favourable scenario for the set of economic variables, this option identifies the relative devaluation of collateral in the Delayed Transition and Current Policies scenarios.

Four collateral update factors, corresponding to variables in the NGFS scenarios, were considered: (i) developments in nominal GDP, applied to commercial real estate and other physical goods; (ii) the house price index, applied to the value of residential real estate; (iii) developments in an estimated equity index for Portugal, applied to the amount of shares, and (iv) the Central Bank intervention rate, applied to the amount of cash and deposits, as these amounts are assumed to be allocated to the credit institution and are expected to be remunerated at this rate.

The physical loss rate for each of the physical collateral categories in each agreement corresponds to the rate of change between the total amount of physical collateral less estimated losses and the initial amount of physical collateral. Equation LGD.4 reproduces this change, where $\sum_c^g Physical\ collateral\ amount^s_{ct}$ corresponds to the sum of the value of collateral units *c* of physical collateral *g* of loan *l* in year *t* in scenario *s* and $\sum_c^g \boldsymbol{Physical\ collateral\ amount_{c,2020}}$ corresponds to the sum of the value of collateral units *c* of physical collateral *g* of loan *l* at the starting point.[28]

[27] The start is the figure identified as at December 2019, which is assumed to be relevant in 2020, the initial period of the long-term projection.

[28] To further support interpretation of the indices, note that each loan agreement may have several units of the same type of collateral *g* (e.g. a loan may have as collateral several properties of the Commercial real estate – offices type).

$$Loss\ rate^{s}_{lg(t,2020)} = \left(\frac{\sum_{c}^{g} Physical\ collateral\ amount^{s}_{ct}}{\sum_{c}^{g} Physical\ collateral\ amount_{c,2020}}\right) - 1 \qquad \text{LGD.4}$$

The physical loss rate of collateral comprises two components: (ii) losses from the temperature increase estimated for each scenario and (ii) the impact of the materialisation of extreme weather events. The value of collateral *c*, in year *t*, scenario *s* and NUTS 3 *N* is defined by equation LGD.5. The two components of physical risk are discussed below.

$$\begin{aligned} &Physical\ collateral\ amount^{s}_{ct} \\ &= Physical\ collateral\ amount_{c,2020} \\ &\times \left(\frac{Dmg^{s}_{t}}{PhC^{s}_{t}} \times TempDev^{s}_{cNt} \times AFR^{s}_{it} + 1\right) \end{aligned} \qquad \text{LGD.5}$$

Losses associated with the NGFS scenarios reflect the effects of chronic climate risks, the intensity of which depends on the severity of the temperature increase considered in each scenario, $\frac{Dmg^{s}_{t}}{PhC^{s}_{t}}$. The NGFS scenarios define an annual amount of total losses from damages to physical assets (measured as losses in economic activity) resulting from the temperature increase, $\boldsymbol{Dmg^{s}_{t}}$, which, after being scaled by the total physical assets estimated for each scenario, $\boldsymbol{PhC^{s}_{t}}$, is allocated to the value of each physical collateral as described in Section 3.

Losses associated with the temperature increase for physical collateral are calibrated by the temperature deviation against the national average estimated for the location of each collateral, $\boldsymbol{TempDev^{s}_{cNt}}$. As in the methodology considered in the PD calculation (PD.12), the estimated loss ratio is weighted by the temperature deviation against the 2020 national average of the district where the collateral is located. The CCR provides information on the location of the collateral underlying each loan, detailed at NUTS 3 level. Since NUTS 3 categorisation does not allow for a univocal relationship between the NUTS region and the district, the univocal relationship between municipality and NUTS 3 and between municipality and district was explored. As a starting point, it was assumed that the temperature deviation of each municipality is equal to the deviation identified for the district to which it belongs. Based on this assumption, temperature deviations at NUTS 3 level refer to the temperature deviation in the municipalities considered in each NUTS 3 class weighted by the assets of the firms of each municipality.[29] The identified temperature deviation for collateral *c* located in NUTS 3 *N* class in year *t,* scenario *s* is represented by variable $TempDev^{s}_{cNt}$.[30]

[29] Two examples of this process are presented: (i) temperature deviation for NUTS 3 "Alentejo Central": given that all municipalities in this NUTS 3 belong to the district of Évora, the implied deviation corresponds entirely to the value of the deviation in the district of Évora. (ii) temperature deviation for NUTS 3 "Alentejo Litoral": all municipalities belong to the district of Setúbal with the exception of Odemira, which belongs to the district of Beja. The total assets of the firms in the municipality of Odemira correspond to 12% of the total assets of the firms with their head office in NUTS 3 "Alentejo Litoral", while the remaining 88% are firms in the district of Setúbal. The value of the deviation for this NUTS 3 is obtained from the expression:

$$TempDev^{NUTS3}_{Alentejo\ Litoral} = 12\% \times TempDev^{District}_{Beja} + 88\% \times TempDev^{District}_{Setúbal}$$

where the share attributed to the district of Beja is derived from the expression:

$$12\% = \frac{\sum_{municipalities\ of\ the\ Beja\ district\ in\ NUTS3\ Alentejo\ Litoral} Total\ assets}{\sum_{NUTS3\ Alentejo\ Litoral} Total\ assets}$$

[30] Note that expression $\frac{Dmg^{s}_{t}}{PhC^{s}_{t}} \times TempDev^{s}_{cNt}$ is equivalent to the expression entered in equation PD.12 $\boldsymbol{CFR^{s}_{it}}$ with reference to the location of collateral *c* and not to the location of the head office of firm *i*, i.e. $\boldsymbol{CFR^{s}_{ct}}$.

When information on the collateral's location was not available, its location was considered to correspond to the firm's head office, which was the case for 26% of the physical collateral units.[31] The temperature deviations considered for each district are the same as those embedded in the PD estimate (Section 3).

Acute climate risks are incorporated using scores calculated by Moody's COD, consistent with the approach considered in the PD estimation (Section 3), translated by term $\boldsymbol{AFR_{it}^{s}}$ in equation LGD.5. Given that Moody's COD information is available with reference to the head office of each of the 50 thousand firms, the measure is applied to the value of the various loan collaterals of firm *i*, irrespective of the actual location of said collateral.

4.3 LGD estimate per agreement

The elements described above define an LGD that establishes a relationship between loan amount and collateral amount, but which is insufficient to estimate the amount recovered by the financial institutions. The V/M ratio allows for an LGD estimate over the projection horizon, under the assumption that the bank will be able to recover the collateral value in its entirety. However, the amount recovered by the institutions is not only related to the value of the collateral at each point in time, it also depends on the institution's ability to take possession of/enforce the collateral and on other characteristics of the contractual relationship.

In order to cater for these additional characteristics in LGD estimates, thereby limiting an overly optimistic approach, the LGD value of each agreement was estimated given the relationship established between (i) the ratio of the banks' LGD in portfolios using an advanced internal ratings-based (A-IRB) methodology to calculate capital requirements (reported in the CCR) and (ii) the realised value of the V/M ratio. The final LGD estimate results from the estimated relationship between the V/M ratio of each agreement and the LGDs reported by the institutions for these agreements.

A fractional regression model was considered which establishes a relationship between the LGD reported by the institutions, the V/M ratio and other contractual characteristics. This model explicitly incorporates the domain of the LGD variable: $\boldsymbol{0 \leq LGD \leq 1}$. Other estimation methodologies could have also been considered, among which the OLS method or the transformation of the dependent variable using a Logit form. However, these two approaches do not by themselves ensure that LGD estimates would fall in the unit interval.

LGD estimation from a fractional regression

The methodology used is formalised in Papke & Wooldridge (1996). For a given fractional variable y, i.e. a variable with domain in the [0;1] interval, considering that $f(y|x,\theta)$ is a conditional density function of y and θ corresponds to a vector of parameters to be estimated, the expected conditional value of y is defined, where:

$$E(y|x) = G(x\theta) \qquad \text{LGD.6}$$

where $G(.)$ is a non-linear function satisfying domain [0;1]. Papke & Wooldridge (1996) suggest that $G(.)$ should be defined as any distribution function, materialised in the article using a Logit distribution function and a Normal distribution function. Intuitively, and taking the Logit functional

[31] This condition added information to approximately 55 thousand physical collateral units, out of a total of 217 thousand units identified in the CCR as at December 2019. The 55 thousand collateral units are associated with around 45,403 loan agreements, in turn linked to 29,258 firms. As the possibility of the firm's head office being different from the collateral's location cannot be ruled out, this effect will be more relevant in firms with more than one establishment. Around 22 thousand of the 29,258 firms have information on the number of establishments, of which only 15% have more than one establishment.

form as reference, this approach considers the Logit transformation of the average value of variable y.[32]

Equation LGD.6 can be estimated using a quasi-maximum likelihood methodology, with Papke & Wooldridge (1996) considering a Bernoulli log-likelihood function.[33] The estimate is consistent and thereby asymptotically normal, if $E(y|x)$ is correctly specified in equation LGD.6.

The dependent variable is the LGD reported by the financial institutions in portfolios of loans to NFCs assessed according to the A-IRB methodology, $\boldsymbol{reported\_LGD_l}$. Only two financial institutions have adopted this methodology and the respective information is included in the CCR at agreement level. Each firm may have multiple LGD observations, as many as the number of loan agreements. For each borrower, LGD may thus vary between agreements with one credit institution and/or between agreements with the two credit institutions.

The explanatory variables include the V/M ratio, $\boldsymbol{\frac{V}{M_l}}$, (which is instrumental in obtaining an LGD projection in the various climate scenarios), the characteristics of the loan collateral and the borrower's characteristics. The remaining variables are not only expected to make a significant contribution to LGD, but also not to show significant changes over the agreement's maturity horizon. Table 7 in the Annex *Descriptive statistics of the variables considered in the LGD regression* breaks down the descriptive statistics of the variables considered in the regression.

The V/M ratio excludes information on collateral identified as Personal guarantees, but the share of this type of collateral in total protection is significant, having an impact on the amount of credit recovered by the institutions. To measure this contribution, the ratio of the collateral amount defined as Personal guarantees to the total collateral amount of each agreement, $\boldsymbol{Share\_pers\_gua_l}$, was considered, together with a quadratic term of this ratio, $\boldsymbol{Share\_pers\_gua^2{}_l}$, which seeks to identify non-linear effects associated with agreements where this type of collateral has a more significant share.

Identifying a firm with overdue loans may contribute to changes in the recovery capacity of banks. This effect is captured by the binary variable $\boldsymbol{D\_overdue_i}$, which identifies borrowers with overdue loans as at December 2019. The effect of a binary variable identifying the loan agreements with amounts overdue as at December 2019 was also considered.

Given that differences were observed in the level of the LGDs reported by the institutions, fixed effects were considered at credit institution level, represented in the equation by variable $\boldsymbol{D\_cred\_inst_{fin}}$. Fixed effects representing different firm sizes, $\boldsymbol{D\_Dimen_i}$, and sectors of activity, $\boldsymbol{D\_act\_sect_i}$, were also considered.

[32] This form is not equivalent to the most common Logit transformation, where the average Logit transformation of y values is considered, as expressed in: $E\left(log\frac{y}{1-y}\middle|x\right) = x\theta$, where $y = \frac{e^{x\theta}}{1+e^{x\theta}}$.

[33] Other methodologies could be considered as discussed in Ramalho et al. (2011). However, using a Monte Carlo analysis, the authors demonstrate that the quasi-maximum likelihood method performs better than other methodologies, in particular when compared to the non-linear least square estimation.

LGD.7 summarises the relationship to be estimated[34]:

$$reported\_LGD_l = \alpha + \beta\left(Ratio\frac{V}{M_l}\right) + \gamma_1 Share\_pers\_gua_l + \gamma_2 Share\_pers\_gua^2{}_l + \gamma_3 D\_overdue_i + \gamma_4 D\_cred\_inst_{fin} + \sum_1^3 \gamma_d D\_Dimen_i + \sum_1^{10} \gamma_r D\_act\_sect_i + \varepsilon_l \quad \text{LGD.7}$$

The contribution of each variable was assessed sequentially by estimating a fractional regression model with a Logit functional form. The results are shown in table 6. From among the various specifications, the equation chosen includes the binary variable identifying any overdue loans in the system (Equation 6 of Table 6). This option is detailed in Annex *On the equation considered*.

All the variables are statistically significant and the effects are in line with economic intuition: the higher the V/M ratio, the lower the LGD of the agreements; the higher the Personal guarantees/Total collateral ratio, the higher the LGD of the agreements, with this effect being more significant for higher ratios. Firms with overdue loans result in higher LGDs. The Annex *On the marginal effects of explanatory variables* discusses the marginal effects in more detail. Finally, Annex *On the adequacy of the Logit functional form in the estimation* discusses the adequacy of the functional form considered, Logit.

The model results allow the LGD of each loan agreement to be estimated over the 2020-50 horizon for each climate scenario. Assuming that the other characteristics remain constant over the projection horizon, the V/M ratio value defined by each climate scenario generates an estimate of the LGD at agreement level in that scenario, as described in equation LGD.8.

$$\widehat{reported}\_LGD_{lt}^{s} = \hat{\alpha} + \hat{\beta}\left(Ratio\frac{V^s}{M_{lt}}\right) + \hat{\gamma}_1 \overline{Share\_pers\_gua_l} + \hat{\gamma}_2 \overline{Share\_pers\_gua^2}{}_l + \hat{\gamma}_3 D\_overdue_i + \hat{\gamma}_4 \overline{D\_cred\_inst}_{fin} + \sum_1^3 \hat{\gamma}_d D\_Dimen_i + \sum_1^{10} \hat{\gamma}_r D\_act\_sect_i \quad \text{LGD.8}$$

4.4 LGD estimate by firm

The foregoing procedure allows the LGD to be estimated at loan agreement level. Once the LGD estimate had been obtained for each agreement, the LGD was estimated at firm level, which is the weighted average of the LGDs of each firm's various agreements, weighted by the loan amount associated with each agreement. Where the firm belongs to an economic group, the estimated LGD corresponds to the average of the LGDs of the loan agreements identified in the CCR for this

[34] Four firm size categories are considered: (i) micro, (ii) small, (iii) medium-sized and (iv) large enterprises according to Commission Recommendation 2003/361/EC. Eleven sectors of activity are considered: (i) Agriculture, Forestry and Fishing, (ii) Mining and Quarrying, Electricity, Gas and Water, (iii) Manufacturing, (iv) Construction and real estate activities, (v) Other construction, (vi) Trade, (vii) Transports and storage, (viii) Accommodation and food services, (ix) Information and communication activities, (x) Consultancy, technical and administrative activities and (xi) Other services. To avoid multicollinearity, a firm size category and a sector of activity category are excluded, namely microenterprises and Agriculture, Forestry and Fishing respectively.

firm and the LGD estimated for all the agreements of the economic group, weighted by the exposure amount.[35]

For some firms, the foregoing procedure did not generate an LGD estimate. This situation is mostly associated with a mismatch between the collateral reporting period and the period for identifying the largest credit exposures, which may lead to the identification of firms with exposure as at December 2021, but which did not yet exist in 2019. The average LGD of estimates by Climate Policy Relevant Sector (CPRS) and firm size was assigned to these firms. Out of the 50 thousand firms considered in the simulation exercise, this assumption was used for approximately four thousand firms.

[35] The definition is illustrated with an example. Consider a firm belonging to an economic group which, after the reallocation of credit among firms in the economic group detailed in Section 2, has a total loan amount where 40% of this exposure corresponds to the firm's own loans and 60% corresponds to loans of other firms in the economic group. The weighted average LGD of this firm in scenario *s*, year *t*, LGD_{it}^{s}, corresponds to:

$$LGD_{it}^{s} = 40\% \times LGD_{firm\ i\ exposure,t}^{s} + 60\% \times LGD_{economic\ group\ exposure,t}^{s}$$

where $LGD_{firm\ i\ exposure,t}^{s}$ is the average LGD of this firm's loan agreements, weighted by the firm's loan amounts, and $LGD_{economic\ group\ exposure,t}^{s}$ is the average LGD of all loan agreements of the firms in the economic group, weighted by the loan amounts of the whole economic group.

Table 6 • LGD estimation using different specifications according to a fractional regression model with a Logit functional form

Variables	Equation 1 LGD	Equation 2 LGD	Equation 3 LGD	Equation 4 LGD	Equation 5 LGD	Equation 6 LGD
(V/M) ratio	-0.0450***	-0.0113***	-0.0152***	-0.0152***	-0.0157***	-0.0157***
	(0.00432)	(0.00223)	(0.00211)	(0.00211)	(0.00207)	(0.00207)
(Personal guarantees/Total collateral) ratio		0.493***	-1.258***	-1.258***	-1.136***	-1.161***
		(0.0137)	(0.0447)	(0.0447)	(0.0448)	(0.0442)
(Personal guarantees/Total collateral)^2 ratio			1.429***	1.429***	1.345***	1.362***
			(0.0341)	(0.0341)	(0.0340)	(0.0338)
Dummy Loan agreement with overdue amounts					0.568***	
					(0.0157)	
Dummy Firm with overdue loans						0.364***
						(0.0101)
Constant	-0.495***	-0.984***	-0.651***	-0.651***	-0.705***	-0.707***
	(0.0121)	(0.0179)	(0.0193)	(0.0193)	(0.0192)	(0.0191)
Observations	87,031	87,031	87,031	87,031	87,031	87,031
Fixed effects Credit inst.	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects Sector	Yes	Yes	Yes	Yes	Yes	Yes
Fixed effects Size	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo-R^2	0.0468	0.0648	0.0857	0.0857	0.121	0.112

Source: Banco de Portugal. | Note: Robust standard deviation in brackets *** p<0.01, ** p<0.05 and *p<0.1.

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Annexes

Descriptive statistics of the variables considered in the LGD regression

Table 1 • Descriptive statistics of the variables considered in the LGD estimation model

		Reported LGD					V/M ratio					Share Personal guarantees					Dummy Firm with overdue loans
Breakdown	Obs.	Average	Stand. dev.	P5	Median	P95	Average	Stand. dev.	P5	Median	P95	Average	Stand. dev.	P5	Median	P95	Share
Total	87,031	0.34	0.14	0.00	0.40	0.47	0.41	2.37	0.00	0.00	1.59	0.88	0.25	0.27	1.00	1.00	0.07
Microenterprises	47,340	0.35	0.14	0.00	0.40	0.47	0.45	2.56	0.00	0.00	1.74	0.90	0.23	0.39	1.00	1.00	0.08
Small enterprises	28,151	0.33	0.13	0.00	0.39	0.45	0.35	2.23	0.00	0.00	1.37	0.90	0.22	0.44	1.00	1.00	0.07
Medium-sized enterprises	8,398	0.33	0.13	0.00	0.36	0.44	0.38	2.01	0.00	0.00	1.72	0.88	0.27	0.00	1.00	1.00	0.07
Large enterprises	3,142	0.38	0.09	0.22	0.42	0.44	0.58	1.09	0.00	0.66	1.01	0.54	0.48	0.00	0.73	1.00	0.03
Agriculture, forest. and fishing	2,625	0.35	0.14	0.00	0.40	0.56	0.40	2.26	0.00	0.00	1.74	0.90	0.23	0.39	1.00	1.00	0.08
Mining and quarrying, electr., gas and water	762	0.33	0.14	0.00	0.39	0.45	0.29	1.02	0.00	0.00	1.28	0.89	0.22	0.46	1.00	1.00	0.11
Manufacturing	17,504	0.34	0.13	0.00	0.39	0.45	0.33	1.61	0.00	0.00	1.33	0.90	0.22	0.40	1.00	1.00	0.08
Construction and real estate activities	7,488	0.31	0.15	0.00	0.35	0.45	1.22	4.60	0.00	0.00	4.97	0.78	0.33	0.00	1.00	1.00	0.08
Other construction	4,332	0.35	0.14	0.00	0.40	0.45	0.25	1.57	0.00	0.00	0.99	0.92	0.19	0.53	1.00	1.00	0.10
Trade	26,202	0.35	0.13	0.01	0.40	0.47	0.31	2.15	0.00	0.00	1.15	0.91	0.20	0.50	1.00	1.00	0.07
Transports and storage	5,677	0.35	0.14	0.00	0.40	0.47	0.14	1.33	0.00	0.00	0.70	0.95	0.15	0.61	1.00	1.00	0.09
Accommodation and food services	5,254	0.33	0.15	0.00	0.40	0.47	0.72	3.44	0.00	0.00	2.80	0.86	0.27	0.23	1.00	1.00	0.06
Information act.	1,568	0.35	0.14	0.00	0.40	0.47	0.21	1.12	0.00	0.00	0.80	0.92	0.19	0.58	1.00	1.00	0.08
Consultancy, tech. and admin. activities	8,443	0.35	0.14	0.00	0.40	0.47	0.35	1.36	0.00	0.00	1.02	0.78	0.38	0.00	1.00	1.00	0.06
Other services	7,176	0.34	0.14	0.00	0.40	0.51	0.39	2.39	0.00	0.00	1.54	0.90	0.22	0.42	1.00	1.00	0.05

Source: Banco de Portugal. | Notes: Figures as at December 2019. 'Stand. dev' refers to standard deviation. The 'Reported LGD' variable corresponds to the LGD reported by the financial institutions in portfolios of loans to NFCs under the A-IRB methodology, the 'V/M ratio' variable corresponds to the ratio of the value of collateral to the outstanding amount, the 'Share Personal guarantees' variable corresponds to the share of collateral from personal guarantees in total collateral taking into account personal guarantees, and the variable 'Dummy Firm with overdue loans' assumes the value of one where the firm has overdue loans on any of its loan agreements with the resident financial system and zero otherwise. Given that it only assumes values between zero and one, the table reports the share of firms with overdue loans. The Construction and real estate activities sector comprises divisions 41 and 68 of the CAE and the Other construction sector comprises divisions 42 and 43.

Additional topics on the estimation of the fractional regression model

On the equation considered

The LGD equation form, which is considered in order to generate LGD estimates for the different loan agreements (Equation 6, Table 6), includes a binary variable that identifies whether the firm has overdue loans in the system, as opposed to a binary variable that only identifies the existence of an overdue amount on the loan agreement (Equation 5, Table 6). This choice is supported by two reasons: (i) information on overdue loans is shared by the various financial institutions through the CCR and (ii) the LGD estimates derived from this equation better approximate the values of the higher percentiles in the distribution of the realised LGD values – Table 8 – even if this equation shows a slightly lower Pseudo-R2 (0.114 when taking into account information on overdue loans in the system against 0.121 when information of an overdue amount on the loan agreement is taken into account).

Table 2 • LGD distribution values: reported values and estimated in-sample values

	5th percentile	Average	Median	95th percentile
Reported	0.0000	0.3403	0.3988	0.4704
Equation 1	0.3060	0.3401	0.3426	0.3749
Equation 2	0.2725	0.3401	0.3477	0.3759
Equation 3	0.2534	0.3401	0.3519	0.3771
Equation 4	0.2534	0.3401	0.3519	0.3771
Equation 5	0.2493	0.3401	0.3491	0.3874
Equation 6	0.2492	0.3401	0.3477	0.4170

Source: Banco de Portugal. | Notes: The values projected for each equation refer to the form presented in table 6. Estimated in-sample values.

On the marginal effects of explanatory variables

The estimated equation does not have a linear form, which makes it impossible to interpret the coefficients as marginal effects. table 9 details the conditional marginal effects calculated with reference to the average value of the remaining independent variables. The impact of the change in the V/M ratio is small compared with the impact of the change in the Personal guarantees/Total collateral ratio. The 1 p.p. increase in the V/M ratio implies a decrease of approximately 0.02 p.p. in LGD and a 1 p.p. increase in the Personal guarantees/Total collateral ratio implies a 0.28 p.p. increase in LGD. However, the positive relationship between the LGD value and the share of personal guarantees identified for each agreement is non-linear and is higher for agreements where the share of personal guarantees is higher.

Table 3 • Conditional marginal effects for equation 6

Variables	Conditional marginal effects
(V/M) ratio	-0.0035***
	(0.00046)
(Personal guarantees/Total collateral) ratio	0.2841***
	(0.0049)
Dummy Firm with overdue loans	0.0810***
	(0.00243)

Source: Banco de Portugal. | Notes: Robust standard deviation in brackets. *** p<0.01, ** p<0.05 and *p<0.1. The estimate of the conditional marginal effect is obtained as the average of the individual effects of the parameter for each observation, when assuming the average value of the remaining explanatory variables.

On the adequacy of the Logit functional form in the estimation

The adequacy of the fractional regression in the LGD estimate depends on the adequacy of the functional form chosen in equation LGD.3, in this exercise assumed as Logit. Papke & Wooldridge (1996), Ramalho et al. (2011) and Ramalho et al. (2014) introduce methodologies for assessing the functional form considered in a fractional regression model. To assess the validity of the assumption for the Logit functional form, four of the tests identified by Ramalho et al. *(* 2014) were considered. Table 10 details these results.

According to the RESET2, GOFF1 and GOFF2 tests, there is no evidence of misspecification of the Logit model. However, the inclusion of a cubic term and the GGOFF test point to a possible misspecification of the model, suggesting potential problems with the current specification. Note that, among the different functional forms, all the coefficients are statistically significant and show the same sign. Thus, the choice was made to keep the Logit functional form and the equation with the form already presented.

Table 4 • Results of the estimation of LGD for different functional forms

Variables	LOGIT LGD	PROBIT LGD	CAUCHIT LGD	LOGLOG LGD	cLOGLOG LGD
(V/M) ratio	-0.0157***	-0.00858***	-0.0352***	-0.00699***	-0.0147***
	(0.00207)	(0.00107)	(0.00630)	(0.000830)	(0.00197)
(Personal guarantees/Total collateral) ratio	-1.161***	-0.688***	-1.303***	-0.630***	-1.009***
	(0.0442)	(0.0266)	(0.0441)	(0.0258)	(0.0368)
(Personal guarantees/Total collateral)^2 ratio	1.362***	0.816***	1.416***	0.768***	1.162***
	(0.0338)	(0.0203)	(0.0362)	(0.0195)	(0.0285)
Dummy Firm with overdue loans	0.364***	0.224***	0.317***	0.231***	0.290***
	(0.0101)	(0.00627)	(0.00830)	(0.00674)	(0.00773)
Constant	-0.707***	-0.445***	-0.518***	-0.118***	-0.904***
	(0.0191)	(0.0115)	(0.0220)	(0.0113)	(0.0158)
Observations	87,031	87,031	87,031	87,031	87,031
Fixed effects credit inst.	Yes	Yes	Yes	Yes	Yes
Fixed effects Sector	Yes	Yes	Yes	Yes	Yes
Fixed effects Size	Yes	Yes	Yes	Yes	Yes
Pseudo-R^2	0.112	0.112	0.113	0.111	0.112
RESET2	0.6657	0.8048	0.000***	0.6697	0.6770
RESET3	0.000***	0.000***	0.000***	0.000***	0.000***
GOFF1	0.6979	0.7326	0.0361*	-	0.5914
GOFF2	0.2963	0.5759	0.0926*	0.5055	-
GGOFF	0.000***	0.000***	0.000***	0.5055	0.5914
P-test					
H1: logit	-	0.0101**	0.000***	0.0382**	0.0000***
H1: probit	0.3490	-	0.000***	0.5669	0.0004***
H1: cauchit	0.000***	0.000***	-	0.000***	0.000***
H1: LogLog	0.0042*	0.0044***	0.000***	-	0.000***
H1: cLogLog	0.0733*	0.6551	0.0047***	0.0192**	-

Source: Banco de Portugal. | Notes: Robust standard deviation in brackets *** p<0.01, ** p<0.05 and *p<0.1. The results of the test on the GOFF1 and GOFF2 functional form correspond by definition to the GGOFF test for the LogLog functional form and the cLogLog functional form, respectively, as detailed in Ramalho et. al (2014).