Annexes

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by
ECB/ESRB Project Team
on climate risk

EUROPEAN CENTRAL BANK
EUROSYSTEM

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European Systemic Risk Board
European System of Financial Supervision

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1 Annex – Surveillance framework

1.1 Methodology for the estimation of households' energy expenditure and emissions

The household analysis creates new energy and emissions datasets in two surveys – the EU Statistics on Income and Living Conditions (EU-SILC by Eurostat) and the Household Finance and Consumption Survey (HFCS by ECB) – based on results from energy and emissions regression models using Household Budget Survey data (HBS by Eurostat), the latter being the only dataset where household energy expenditures are recorded. While carbon emissions are not available in the HBS, they are estimated by combining individual energy expenditure levels and emissions factors for each HBS fuel. HFCS and EU-SILC were chosen due to the availability of variables which are aligned with the financial sector, namely outstanding balance on mortgage and mortgage payments, respectively.

The estimation process, which is carried out separately in each country, involves several steps which are also summarized in Figure A.1:

1. Creating a household CO2 emissions variable in the Household Budget Survey (HBS):

    - For each type of fuel expenditure in the HBS, such as electricity, gas, liquid fuels, and heating oil, the expenditures are converted into quantities by dividing them by the energy prices in the HBS year.[1] These quantities are further converted into emissions by multiplying them by the corresponding emission factors.[2] The emissions from each type of fuel are summed to calculate the total household CO2 emissions. Solid fuels are excluded due to missing data on fuel type, such as wood or coal.

2. Creating a household energy expenditure variable in the HBS:

3. For each fuel expenditure in the HBS (electricity, gas, liquid fuels, and heating oil), the expenditures are adjusted for inflation based on the specific fuel inflation rates between the HBS year (2015) and the EU-SILC (2018) and HFCS (2021). The adjusted expenditures for each type of fuel are summed to create the total household energy expenditure for the EU-SILC and HFCS datasets.

4. Creating lists of regression variables, which are the determinants of energy consumption.

5. Conducting Ordinary Least Squares (OLS) regressions using HBS data only.

6. Creating energy and emissions estimates in the EU-SILC and HFCS datasets using coefficient values from Step 4.

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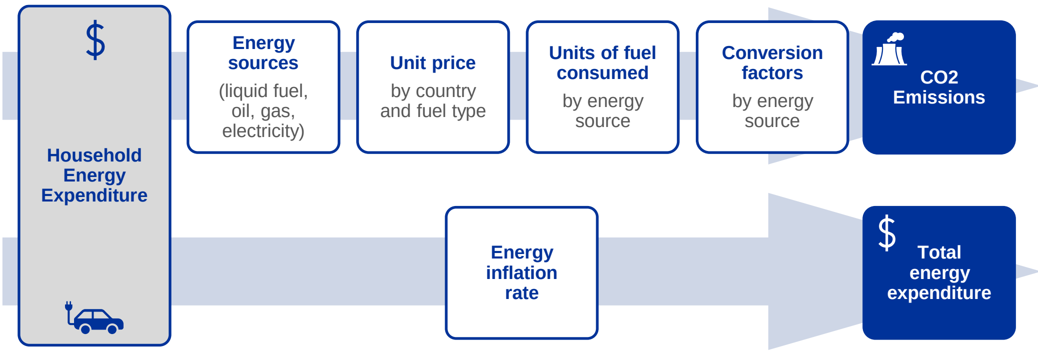
[1] Fuel prices sourced from Eurostat [**source** and **source**] and European Commission [**source**]

[2] Emissions factors sources from the Sustainable Energy Authority of Ireland [**source**]

Figure A.1
Overview of the methodology



Sources: ECB/ESRB Project Team.

1.2 Methodology, data and supplementary material on insurance protection gap

The analysis[3] aims to quantify the size of premiums written associated with an increase in insurance penetration in the EU, while also estimating the impact on public finances when climate-related fatalities occur together with insurance sector defaults. The focus is on coastal and river flooding events only. Data for coastal and river floods are outsourced from latest version of the Risk Data Hub[4], an EU-wide web-based geographical information system platform developed by the Joint Research Centre of the European Commission. The database provides georeferenced exposure data for various assets, such as buildings, population, critical services, and the environment, together with a vulnerability indicator. The former aims to assess exposure to natural hazards, while vulnerability refers to the predisposition of the exposed elements to withstand natural hazards and is assessed as a multidimensional social, economic, political, environmental, and physical indicator.

To calculate the expected annual human loss (EAHL) over 1 year,[5] the corresponding exposures of people (EP) under different return periods are weighted using the probability of occurrence ($POc, period$),[6] where the "return periods" are estimates of the interval of time between events.[7]

$$EAHL_i = \sum_{period} EP_{i,period} \times PO_{C,period}$$

[3] The analysis presented is based on Bellia et. al (2023) for which we refer for further details.

[4] **https://drmkc.jrc.ec.europa.eu/partnership/Scientific-Partnerships/Risk-Data-Hub**

[5] The choice of one year time horizon is justified by the fact that contracts for non-life insurances are usually short term, while life insurance contracts are usually long-term.

[6] We focus on human exposure which represent the totality of fatalities, namely people whose households have been affected by the flood and people that got injured.

[7] For example, a return time of 100 years indicates that the event will occur once in 100 years on average, therefore the probability a similar event could occur in the same interval of time is 1% (1/100). A more technical explanation of these topics are provided in the **DRMKC - Risk Data Hub website.**

To evaluate the monetary loss of each country i due to flood events, we start with the 2020 GDP at current market prices and apply the share of population affected ($EAHL_i$) over the total population of a country.[8] As exposure alone is not sufficient to determine the final risk, as it is possible to be exposed but not vulnerable to a particular hazard, the expected economic loss (EEL_i) is calculated by rescaling the monetary loss using the vulnerability index (V_i) of each country.

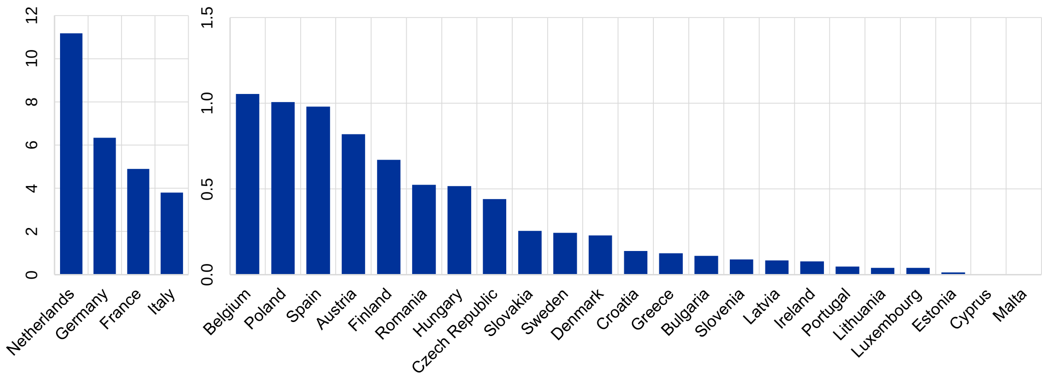
$$EEL_i = GDP_i \times \frac{EAHL_i}{Total\ population_i} \times V_i.$$

Chart 1 shows the size of average expected economic losses per country due to flood events. The Netherlands is the country most affected, followed by Germany, France, and Italy. Interestingly, while the Netherlands has the highest risk of coastal flood-related hazards, Germany is the most exposed to river flood losses. At the EU level, the total amount of average expected economic losses (in one year) due to flood events amounts to around EUR 33 billion.

Chart A.1

Average expected economic loss, by country

(y-axis: EUR billion)



Source: JRC Risk Data Hub, Eurostat, JRC elaboration

To obtain the share of insured natural-related losses, our model relies on estimates of the insurance penetration, as published in the EIOPA dashboard. Ratios for insurance penetration are applied to the average expected loss from flood events to estimate the size of technical provisions related to flood events in each country. Climate-related technical provisions (for floods) are assumed to be equal to the share of average economic loss transferred to the insurance sector, depending on the actual insurance penetration ratio:

$$\mathrm{TP}_{\mathrm{flood,i}} = \mathrm{IP}_{\mathrm{flood,i}} \times \mathrm{EEL_i}$$

8 Both statistics on GDP and total population are sourced from Eurostat.

1.2.1 Estimation of insurance premiums

If the technical provisions represent the risk-weighted costs, the premium represents the revenues of the insurance business. These variables should in theory move together: an increase in insurance coverage will be reflected in the technical provisions and subsequently in the amount of written premiums.[9] To model the joint dynamics of technical provisions and premiums, considering their common past history, we estimate a set of Vector Error Correction Models (VECM). The model includes an underlying long-run relationship among the series (cointegration relationship) and a short-run dynamics. More formally, let a $K \times 1$ vector of variables y_t $(t = 1, \dots, T)$ that are integrated of order 1, or $I(1)$.[10] The variables are said to be cointegrated with a cointegration vector β, if there exists a vector β such that βy_t is a vector of $I(0)$ variables. The formal representation of a VECM(p) is:

$$\Delta y_t = v + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-1} + \varepsilon_t$$

where $\Pi = \sum_{i=1}^{p-1} A_j - I_k$ and $\Gamma_i = -\sum_{j=i+1}^{j=p} A_j$. To assess the order of cointegration of the VECM, we use the Johansen tests for cointegration (see Johansen, 1995), which applies a two likelihood-ratio test for inference on the rank r, obtaining the so-called trace statistic.[11]

The final elasticity between technical provisions and gross premiums is estimated by calculating the orthogonalized impulse response function (OIRF). For VECM, the orthogonalized shock (in our case, a shock on technical provisions) has a permanent effect on the gross written premium. We estimate the OIRF for each VECM eight steps ahead, and we choose the last value of the OIRF as a reference for the subsequent calculations. In this case, a one-unit shock on the technical provision would increase the gross written premium by the value of the OIRF at the last step.

Finally, to obtain the final expected gross premium to be written for Member State i, EGP_i, we multiply the expected economic losses EEL_i by the value of the orthogonalized impulse response function for Member State i, $OIRF_i$ in the last step.

$$EGP_i = EEL_i \times (1 + OIRF_i)$$

To evaluate the amount of EGP_i that need to be written in order to harmonize the penetration rate at 50% (EGP_i^{50}) or 75% (EGP_i^{75}) for each Member State, taking into account the actual penetration rate $IP_{flood\ (i)}$, we calculate the quantities as follows:

$$EGP_i^{50} = \max\left(0.5, IP_{flood\ (i)}\right) \times \mathrm{EEL_i} \times (1 + OIRF_i)$$

$$EGP_i^{75} = \max\left(0.75, IP_{flood\ (i)}\right) \times \mathrm{EEL_i} \times (1 + OIRF_i)$$

[9] Another possibility is to assume that the expected economic losses $\mathrm{EEL_i}$ translate directly in pure premiums. This estimate excludes insurers margins and additional costs, but also potential economies of scale. The results using this approach is however very close to the one using the VECM (differences are around 2-3% of estimated gross written premiums.

[10] Integrated or order 1, or I(1) means that the first difference $\Delta x_t = x_t - x_{t-1}$ is stationary, or I(0).

[11] The VECM is estimated with one lag, and the Johansen test is estimated using two lags. However, the results are similar when using three or four lags. The trace statistics and the tabulated critical values are used to assess whether a cointegration relation exist. Additional details and tabulated results are available in the main paper (Bellia et. al, 2023c). Then, the OIRF of the VECM is estimated in order to obtain the elasticity of TP w.r.t premiums, and the potential increase of gross premiums is calculated once the penetration rate is increased for some MS

1.2.2 Economic losses on public finances

We assume that the insurance sector can be regarded as a portfolio of counterparty risks. Within the portfolio, each insurer has a small but non-zero probability of causing a liability to policyholders upon default. Upon default of an insurance undertaking, the exposure at default (EAD_c) is the maximum amount of the company's liabilities to claimants, beneficiaries, and the insured. The loss given default (LGD) is the percentage loss that will effectively be incurred on the exposure once the defaulted company's recovery rate is considered. With the one-year probability of default of the company given by PD_c, the expected liability (EL_c) for a single company "c", over the period of one year, is given by:

$$EL_C = LGD \times EAD_C \times PD_C.$$

Since we are not interested in a single insurance undertaking, but in all insurance companies at the individual country level (or even at the aggregate EU27 level), we can make some simplifying assumptions to estimate the loss distribution of the insurance sector in each country, without the need to estimate the loss distributions of individual insurance undertakings (European Commission, 2010 and European Commission, 2021c). As different insurers might have different loss rates, information on the distribution of losses from insurance defaults is necessary to assess the effective risk the public is exposed to. The loss rate distribution can be seen as the loss rate on a portfolio of exposures to several insurance undertakings. Specifically, we use the Vasicek (2002) model to define the event of default, as occurring when the insurer's asset value falls below a predetermined threshold. The value of L_i for country i represents the maximum loss that should not be expected to exceed in one year with a probability level α is given by:12

$$L_i = EAD_i \times LGD \times N\left[\frac{\sqrt{\rho + \delta(1-\rho)}\, N^{-1}(1-\alpha) + N^{-1}(PD)}{\sqrt{1-\ \rho - \delta(1-\rho)}}\right].$$

Some notes on the parameters used in our analysis:

- The LGD is set equal to 15% as in European Commission (2021c);
- PD is fixed at 0.5% for simplicity, being this value the maximum probability of default, which should be attained in the Solvency II framework and therefore marks an upper bound for the probability distribution of defaults.
- ρ is the correlation among defaults and has been set at 20%, consistent with European Commission (2021c).
- δ is the concentration exposure term, tackling the fact that a portfolio of insurers consists of a discrete number of relatively large exposures. This correction term is calculated on the basis of the companies' market share, as a proxy for the relative size of individual exposures in the

[12] It is one of the most widely applied tools for quantitative financial risk management and it is mostly used to assess default portfolio risk across a variety of business sectors, including the insurance sector. The framework of Vasicek (2002) hinges on the asymptotic behaviour of an extended Merton model (Merton, 1974) when the number of exposures in the portfolio of insurers goes to infinity.

portfolio,13 by summing the squares of the relative sizes of the markets shares. We estimate δ separately for each country based on information from EIOPA on the market share of the top 1, top 3, top 5, top 10, and top 15 insurance undertakings. We refer to European Commission (2021c) for more details.

- EAD_i is given by the sum of TP_i, our best estimate of liabilities and risk margin and SRC_i as the total amount of funds that an insurer is required to hold to ensure that the company will be able to meet its obligations with a probability of at least 99.5%

$$EAD_i = SCR_i + TP_i$$

In the baseline case, we consider only the one-year expected liability at country level EL_i and the average expected average expected economic loss (AEL_i) estimated using Risk Data Hub values. Specifically, we compare the situation with the actual insurance penetration rate with a scenario with harmonized 75% insurance penetration rate for flood events across all member state. The baseline expected losses (BL_i) are thus calculated as follows:

$$BL_i = EL_i + \left(1 - \mathrm{IP}_{\mathrm{flood,i}}\right) \times AEL_i$$

where $\mathrm{IP}_{\mathrm{flood,i}}$ represent the actual penetration rate, which will be increased up to 75% for Member States that does not reach this threshold. This amount represents the potential expected losses, with a one-year time horizon, for flood-related events.

1.3 Supplementary resources on physical risk amplification and supply chain analysis

The Input-Output model used for the analysis presupposes Leontief production functions, where input categories are substitutable at a global level. After climate shocks are exogenously introduced to the model supply chain network, some country-sectors will face shortages of key production inputs. For example, the automotive industry in Europe might face shortages of technology components if their suppliers in, let us suppose, South Asia faced a production disruption due to localised climate events realising in South Asia. The European automotive industry would be able to maintain pre-shock production level only if they were able to source the missing components from elsewhere in the world, that is, if they could reallocate their input supply chains. This depends on the availability of extra components in other parts of the world and the cost at which reorganising supply would happen. Availability depends on the inventory levels of country-sectors around the world, which is depends on the model calibration and the exogenous shock propagation. The cost is a model parameter which is labelled “trade reallocation capacity” and represents the percentage of each input which can be reallocated. The parameter ranges from 0, full reallocation, to zero, no reallocation is possible. Both represent extreme cases but are useful for understanding the range of outcomes.

[13] The calculation methodology is the same as that of the calculation of the Herfindahl–Hirschman Concentration Index (HHI), used widely in competition literature.

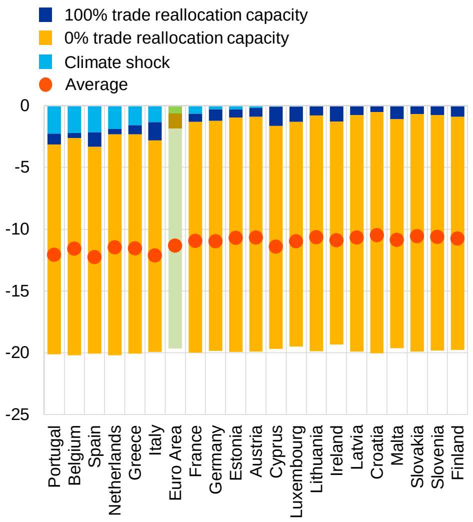
Euro area countries exposure to direct physical risk is low and heterogeneous, while the impacts from cross-border transmission pose significant and more homogeneous challenges. Only six Euro area countries are expected to suffer direct GDP losses due to extreme climate hazards of more than one percentage point, with the euro area average being 0.6% (Chart 2a, light blue).[14] Taking into consideration the cross-border transmission of risks, however, shows that the ultimate GDP impacts would be significant for all euro area countries. The predicted impacts depend on the capacity of countries to reallocate their input supply and could be multiplied up to 30 times the initial impact (Chart 2a).[15] In a best case scenario where countries could reallocate the entirety of their input sourcing, some euro area countries which are highly dependent on trade would suffer GDP losses significantly higher than what would be suggested by looking at the simple direct exposure to climate physical risks.

Chart A.2

Sectoral impacts are heterogenous, and show vulnerabilities for loan exposures

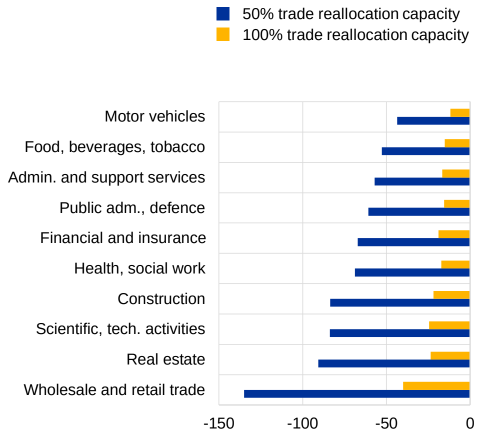
a) GDP losses across euro area countries due to direct climate physical risk and amplified through trade interconnections

(y-axis: GDP changes in pp)



b) Sectoral GVA losses, aggregated at the euro area level

(y-axis: EUR billion)



Sources: OECD, SP Global, ECB calculations
Notes: Panel a): The GDP losses through trade amplification are simulated through an Input-Output model developed at the ECB. A 100% Trade Reallocation Capacity (TRC) parameter implies no cost in reorganising supply chains. For the exogenous climate shock, an adverse climate scenario is considered, i.e., the RCP8.5 scenario by 2050 with no adaptation measures and where all risks materialize simultaneously. Note that the result that taking value chains into account can lead to greater domestic GDP losses also applies to other climate scenarios. Panel b): a breakdown of the predicted impacts on euro area sectors' GVA under two trade reallocation scenarios. The "partial" trade reallocation parametrization implies that the global supply network can reorganise up to 80% of the input sourcing at no cost.

[14] These countries are Italy, Greece, Netherlands, Spain, Belgium, Portugal.

[15] Note that the no trade reallocation capacity is an extreme scenario which is highly unlikely to materialize

On the euro area level, a few sectors are particularly exposed, with trade reallocation playing a significant role in determining the magnitude of outcome. Wholesale and retail trade, real estate, and scientific and technical activities are the sectors that will face the highest losses at euro area level from cross-border transmission of climate risks (Chart 2b). These sectors also represent an important source of risk for the financial system, because of the relatively large banks' loan book portfolio exposure to these sectors. The difference between the partial and full trade reallocation capacity scenarios impacts shows the importance that restructuring supply chains can have. For example, the real estate sector would shift from the second largest impact to the third. Notably, also the health sector would fare relatively better if trade reallocation was available, which can have important welfare implications.

1.4 Supplementary indicators

1.4.1 Relative carbon intensity

The relative carbon intensity (RCI) measures the position that a given obligor, issuer, counterparty or country occupies in the carbon intensity distribution of its peers. Individual firms can deviate from the sectoral carbon intensity due to firm characteristics like their product mix, technological portfolio, or reliance on specific energy sources. The degree to which carbon intensity varies across and within sectors is represented in Chart 3 (panel a), based on a sample of 4621 counterparties. For instance, the 10th to 90th quantiles of the NACE C23 (Manufacture of other non-metallic products) range from 56,3 to 5437 tC02eq/m$, whereas the NACE D35 (Electricity, gas and steam) vary from 11,2 to 3696,8. The large intra-sector variability means that sectoral means or medians can significantly under or overstate the carbon intensity of individual firms.

To complement sectoral assessments, the RCI is a firm-level metric that can be universally applied to any asset class. Crisostomo (2022) employs the RCI to consistently analyse the carbon intensity of more than 15000 different financial instruments across equities, corporate bonds, sovereign debt and investment funds categories. Specifically, the RCI can be used to perform ISIN-level calculations that improve the climate risk assessment of financial portfolios. Similarly, it can be employed to differentiate among the best and worst-in-class in each economic industry.

The RCI calculation requires an appropriate probability distribution to describe the carbon intensity of each economic sector and asset class. Crisostomo (2022) shows that the lognormal distribution model reproduces the empirical features observed in carbon intensity data, delivering an increasing goodness-of-fit as the number of observations increase, as captured by the Q-Q plot in Chart 3 (panel b).[16]

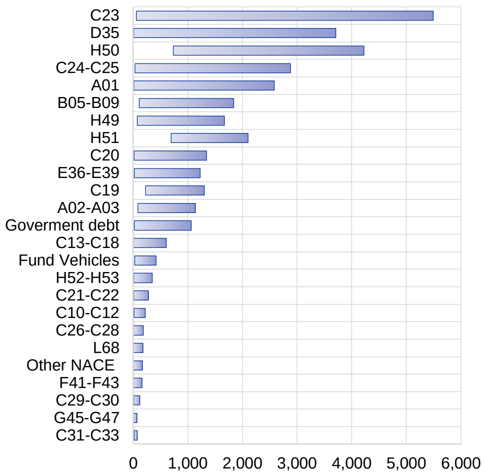
[16] The chart exhibits the lognormal Q-Q plot of CO2 intensity for a sample of 4621 counterparties. Crisostomo (2022) shows that for all segments with sufficient sample size (i.e.: more than 30 counterparties), the average R2 of the sectoral Q-Q plots is 0,9565 [range: 0,8684 to 0,9946], hence providing a good fit to carbon intensity data.

Chart A.3

Sectoral variability of carbon intensity and lognormal Q-Q plot

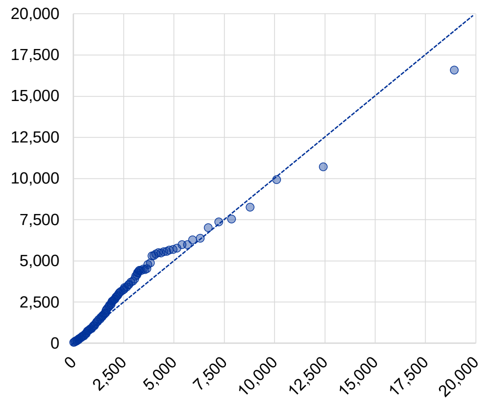
a) C02 intensity by economic segment, from 10th to 90th percentile

(tC02e/m$)



b) Lognormal Q-Q plot of CO2 intensity

(tC02e/m$)



Source: Crisostomo (2022). Carbon intensity and economic sector is obtained from a sample of 4621 counterparties using Refinitiv, Bloomberg and MSCI data.
Notes: Panel a: Carbon intensity is calculated as the total direct (scope1) and indirect (scope 2) CO2-equivalent emissions in tones normalized by net sales or revenue in million US dollars. (tC02e/m$). (right): Lognormal Q-Q plot of C02 intensity for a sample of 4621 counterparties.

1.4.2 Forward-looking WACI

Exposure to transition risk reduces by almost 50% until 2030 in a sudden transition risk scenario due to rapid emission reductions and steady economic growth. The weighted average carbon intensity (WACI) measures the carbon intensity of banks' corporate loan portfolios at the sector-level.[17] The largest exposure to WACI is towards the mining sector, followed by the electricity sector (Chart 4, panel a). The WACI rebounces in the second year of the transition due to adverse macroeconomic conditions, however, gradually decreases afterwards due to emission reductions (almost 50% between 2023 and 2027) and steady growth in gross value added between 2024 and 2027 (Chart 4, panel b).

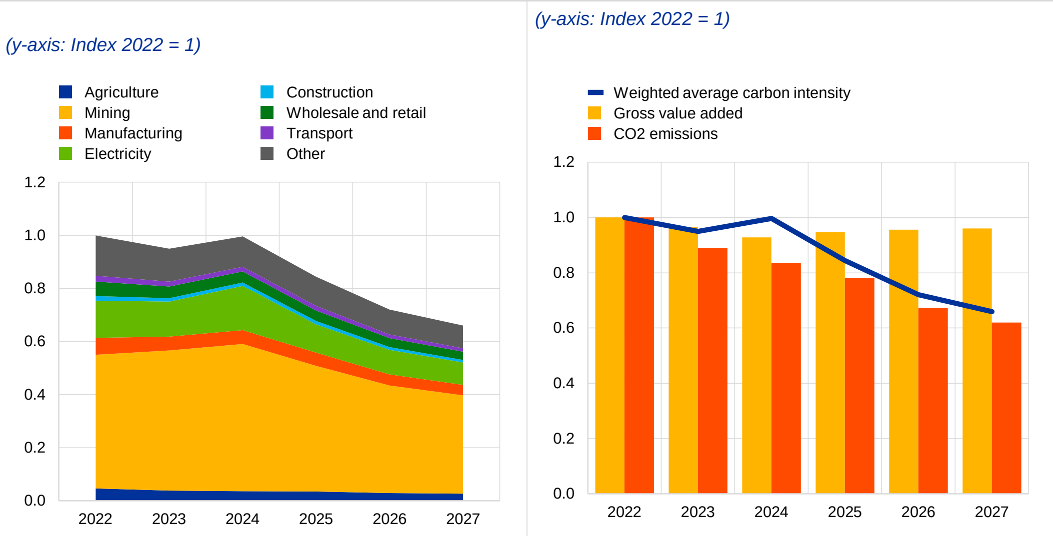
[17] Loan-weighted emission intensity at the sectoral level is defined as GHG or CO2e emissions over gross value-added (GVA), weighted by sectoral loan-share: $\sum_s \frac{E_s}{GVA_s} x \frac{L_s}{L}$, with E_s representing absolute emissions and L_s loans by sector, where L stands for total loans. The forward-looking information used for its computation comprise projections of firm-level emissions (scope 1, 2 & 3 emissions) and sector-level gross value added (GVA), projected with the ECB top-down climate stress test. Notably, the methodology and data sources differ from that presented in Section **Error! Reference source not found.** for t he backward-looking WACI, which abstracts from the sectoral dimension, focusses only on Scope 1 emissions, and uses revenues instead of GVA as measure for production value.

Chart A.4

Exposure to a sudden transition risk decreases over time due to rapid emission reductions and economic recovery

a) Change in forward-looking weighted average carbon intensity across time and sectors under a sudden transition scenario

b) Evolution of weighted average carbon intensity components over time under a sudden transition scenario



Sources: ECB calculations on Orbis, Urgentem (acquired by ICE), Eurostat, IRENA, IPCC, BMPE macroeconomic projections, NGFS, Register of Institutions and Affiliates Database and Anacredit.
Notes: The charts comprise aggregate information based on a sample of 2.9 million euro are non-financial corporations (NFCs). The forward-looking absolute emissions refer to firm-level scope 1, 2 & 3 absolute emissions as of 2021 from Urgentem aggregated at sector-level and projected forward according to the implied country-sector emission pathways of the sudden transition scenario. Forward-looking GVA refers to country-sector level GVA projected forward based on the GVA pathways of the sudden transition scenario. Sectors refer to NACE Level-1 letters. "NACE" stands for Nomenclature statistique des activités économiques dans la Communauté Européenne (Statistical classification of economic activities in the European Community).

1.4.3 Forward-looking indicators of vulnerability to transition risk

The vulnerability towards transition risk is only partially correlated with borrowers' emissions and highly concentrated among sectors and loan portfolios. The largest increase in sector-level transition-to-credit-risk intensity (TCI) is observed in the electricity sector due to the strong deterioration of this sector's credit risk due to transition risk (Chart 5, panel a).[18] While the euro area aggregate TCI is already recovering from 2025 onwards, it remains at around two times its value in 2027 relative to 2012, mostly attributed to the vulnerability of the mining, electricity and manufacturing sectors. Banks' carbon price sensitivity only partially correlates with their loan-weighted absolute emissions (Chart 5, panel b). This indicates that it is not only borrowers'

[18] In the ECB top-down climate stress test framework, energy-intensive sectors are the most affected by transition risk due to two main reasons: First, for sectors with a large share of brown energy consumption in their energy mix, rising energy expenses due to rising energy prices deteriorate their profitability. Second, energy-intensive sectors accumulate large investments to mitigate their Co2 emissions and increase the share of renewable energy in their energy mix. The utility sector, in particular, is expected to bear the largest share in renewable energy investments as it is expected that the majority of carbon-neutral energy will be distributed by the electricity sector via renewable-based electricity,

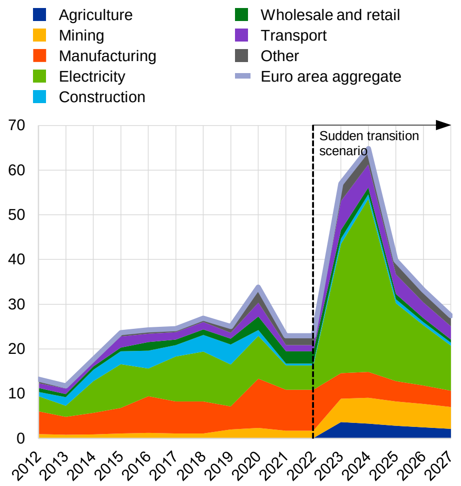
emissions but additional factors, such as the response of borrowers' profitability and indebtedness to the rising carbon prices that determine the loss increase in their loans.

Chart A.5

The vulnerability towards a sudden transition scenario is concentrated in a few sectors and loan portfolios

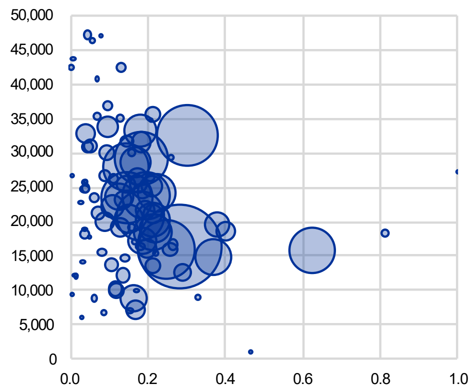
a) Change in forward-looking transition-to-credit-risk intensity across time and sectors under a sudden transition scenario

(y-axis: EA aggregated TCI)



b) Bank-level climate risk sensitivity (CRS) and loan-weighted emissions by 2027 under a sudden transition scenario

(y-axis: loan-weighted absolute emissions, x-axis: min-max normalized CRS score, bubble size indicates size of absolute expected losses until 2027)



Sources: ECB calculations on Orbis, Urgentem (acquired by ICE), Eurostat, IRENA, IPCC, BMPE macroeconomic projections, NGFS, Register of Institutions and Affiliates Database and Anacredit.

Notes: Panel a: The time series covers both inferred and reported emissions for 1,250 non-financial corporations (NFCs), which comprise on average 10% of AnaCredit exposures over time. Backward-looking results of the TCI assume that the credit risk component (PDs) does not already consider climate risk. The components of the forward-looking TCI are assumed to follow the pathway of the sudden transition scenario. Two different underlying sources for emissions data are used. Historical TCI uses emissions based on firm-level data from Urgentem (acquired by ICE). The forward-looking emission intensities refer to firm-level scope 1, 2 & 3 absolute emissions over revenues as of 2021 from Urgentem and projected forward according to the implied country-sector emission pathways of the sudden transition scenario and firm-level projection of revenues. Panel b: Results for corporate loan portfolios of euro area Significant Institutions (SIs) are presented. Absolute emissions refer to scope 1, 2 & 3 Co2 emissions. Sectors refer to NACE Level-1 letters. "NACE" stands for Nomenclature statistique des activités économiques dans la Communauté Européenne (Statistical classification of economic activities in the European Community).

2 Annex – Climate scenario-based exercises in the EU

2.1 Overview of climate scenario-based exercises conducted in the EU

Table A.1
Overview of climate scenario-based exercises conducted in the EU

Application	Purpose	Scenario used	Coverage	Key findings
[European Banking Authority] One-off Fit-for-55 climate risk scenario analysis (publication in 2025)	• Assessing the resilience (until 2030) of the financial sector to transition risks and systemic risks in line with the Fit-for-55 package • Transition and systemic risks considered, top-down approach, static balance sheet assumption	Short-term scenarios	Banks, insurers and market participants involved in financial markets.	• Exercise is still ongoing
[Banca d'Italia] Assessing credit risk sensitivity to climate and energy shocks (2023)	• Assessing the transmission channels of energy shocks and firm exposure in detail • Transition risks considered, top-down approach, static balance-sheet assumption	Short-term scenarios	Banks	• The effect of a carbon tax on the credit-worthiness of Italian non-financial corporations would be contained and diversified across industrial sectors • See focus 2.2.4
[Banco de España, CNMV and DGSFP] Biennial report on climate change risks to the financial system (sep-23)	• Assessing the impact of transition shocks on the Spanish economy • Transition and physical risks considered, top-down approach, dynamic balance sheet assumption	ECB-ESRB scenario with NGFS estimates and Banco de España estimates of variables	Banks, investment funds and insurers	• Transition to zero-carbon economy triggers a more moderate adverse impact if it is gradual and anticipated • See Focus 2.2.1, 2.2.2 and 2.2.5
[Banco de Portugal] Climate scenario analysis: credit risk of non-financial corporations (jul-23)	• Assessing credit risk impact of the materialization of climate risks in exposures of Portuguese banks to NFCs • Assessing firm-level probability of default (PD), loss given default (LGD) and expected losses • Transition and physical risks considered, top-down approach, static balance sheet assumption	NGFS long-term climate scenarios (Net-zero 2050, Delayed Transition, and Current Policies)	Banks	• In the short term, credit risk increases more in the transition scenarios • In the long run, credit risk is higher in the current policies scenario due to growing materialization of physical risks • There are heterogeneous effects among firms based on activity sector and geographic location
[Banque Centrale du Luxembourg] LU climate risk exposures and stress testing (2023)	• Assessing climate risk exposures of the LU financial system • Conducting a first stress test for the LU banking sector • Transition risks considered, top-down approach, static balance sheet assumption	Long-term scenarios	Banks, investment funds	• Importance of an orderly transition • In the case of a disorderly transition, the long term benefits outweigh the short term costs of the transition.
[Deutsche Bundesbank] Climate transition stress test for the German financial system (nov-23)	• Assessing climate risk exposures of the German financial system • Transition risks considered, top-down approach, static balance sheet assumption	NGFS long-term scenario (Net Zero 2050), short-term scenario developed internally	Banks, investment funds and insurers	• Transition to zero-carbon economy leads to manageable losses • Carbon price adjusting in a more disorderly fashion triggers increased risks to financial system • See Focus 2.2.3
[Banca d'Italia] Climate change and credit risk: the effect of carbon taxes on Italian banks' business loan default rates (2022)	• Assessing the impact of the energy transition on the Italian bank's credit risk via the introduction of different carbon taxes • Transition risks considered, top-down approach, static balance sheet assumption	NGFS long-term scenarios	Banks	• the introduction of carbon taxes within the range of €50-200 per ton,with low default rates does not have a sizeable effect on the default rates at the sector level in the short term • See Focus 2.2.4
[EIOPA] IORP Stress test (2022)	• Assessing EEA IORPs resilience to climate risks • Transition risks considered, bottom-up approach, static balance sheet assumption	Short-term scenarios	EEA IORPs	• IORPs have exposures to transition risks • The stress test scenario provoked a sizeable overall drop of 12.9% in assets, corresponding to losses of some €255 billion

[De Nederlandsche Bank] Evidence from a stress test for the Netherlands (2021)	• Assessing the impact of floods on financial stability • Physical risks considered, top-down approach, static balance sheet assumption	Short-term scenarios	Banks	• Capital depletions would increase quickly in case more severe floods hit the densely populated part of the Netherlands • See focus 2.2.6
[ACPR] A first assessment of financial risks stemming from climate change (2020)	• Raising financial institutions' awareness of the risks induced by climate change and their transmission channels • Transition and physical risks considered, bottom-up approach, static balance sheet assumption up to 2025 then dynamic balance sheet assumption up to 25050	NGFS long-term scenarios (orderly and disorderly transition and physical risk scenarios	Banks and insurers	• The energy transition, necessary in order to comply with the Paris Agreement, requires significant efforts to adjust the system and economic structures
[EIOPA] Sensitivity analysis (2020)	• Assessing insurers exposures to climate risks • Transition risks considered, top-down approach, static balance sheet assumption	Long-term scenarios	EEA solo insurers	• Losses on equity investments in the high-carbon sector can be high • Impact on the balance sheets of the insurance sector is counter-balanced both by investments in renewable energy and the general diversity of the insurer's portfolios

2.2 Focus on specific exercises

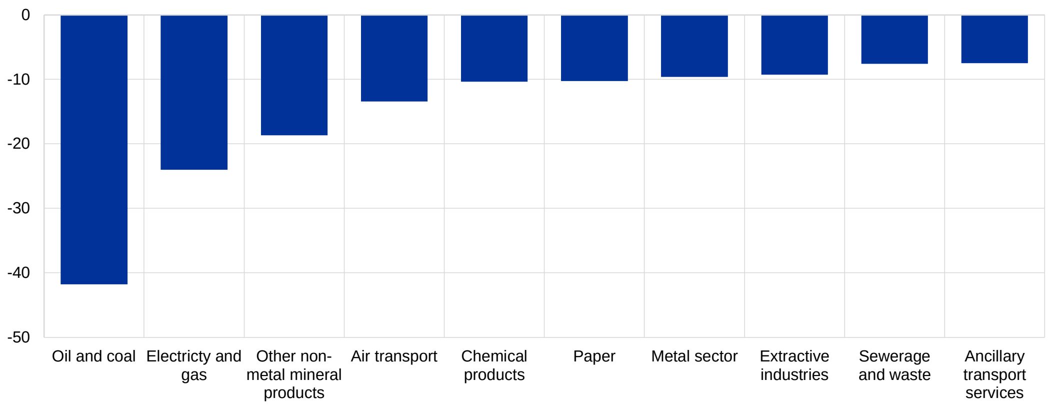
2.2.1 Sectoral transition scenarios in Spain

Similar to the Deusche Bundebank (Frankovic, 2022) or the Banque de France (Lisack and Devulder, 2020), Banco de España has developed a general equilibrium model – the Sectoral Carbon Tax model (hereafter CATS) – to simulate the impact of transition shocks on the Spanish economy[19]. The model has a detailed sectoral structure[20] and can simulate the impact of shocks to the price and coverage of greenhouse gas emission allowances by considering sectoral asymmetries arising from the energy intensity of each industry, the source of that energy, and the interdependencies with other industries derived from input-output tables. It has been used to build transition risk scenarios for stress tests of the banking sector over a three-year horizon, with GVA growth paths included in the models of PD of each bank's portfolio of loans to firms[21].

Chart A.6

Impact of a disorderly transition scenario on the growth of real sectoral gross value added in Spain in the medium term

(y-axis: difference in percentage points of the cumulative change over three years compared to the baseline scenario)



Sources: AMCESFI biennial report on climate change risks to financial system (2023) and Banco de España.
Notes: The charts shows ten most affected sectors according to the ranking of the disorderly transition scenario.

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[19] See Aguilar, González and Hurtado (2022) for more details. New features are being developed under a new version of this model, called CATALIST, and the methodological paper will be published soon.

[20] The CATS model enables the projection of different GVA growth paths for 51 non-energy sectors and for two energy production sectors ("fuel" and "electricity") under different narratives.

[21] In 2021, Banco de España run an initial analysis of transition risks for Spanish banks reflecting shocks to the real GVA growth paths due to changes to environmental legislation, linked to higher prices and the extended coverage of the emissions trading system. The exercise showed that the short-term impacts of the transition scenarios on the profitability and solvency of the Spanish banking sector are moderate, although the sectors most linked to greenhouse gas emissions would be the most affected. Given that these exposures represent a very limited fraction of total bank lending to business activity, the Spanish banks would be able to absorb the materialisation of the short-term transition risks envisaged in this exercise. Further information can be found in the article "An initial analysis of energy transition risks using the Banco de España's FLESB stress-testing framework". BdE Financial Stability Review, Autumn 2021.

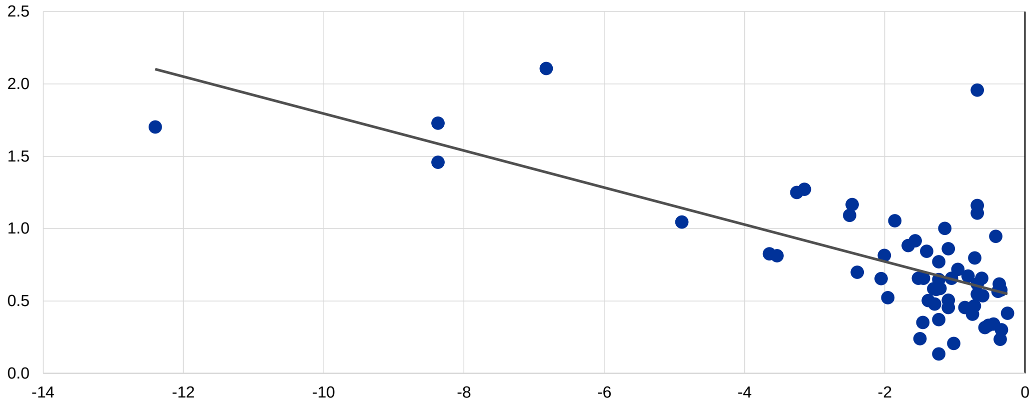
More recently, the CATS model has been used to build real GVA paths for the Spanish economy in line with the ECB/ESRB (2022) disorderly transition scenario. The results of the model and the related stress test have been published in the AMCESFI Biennial Report on Climate Change risks to Financial System in 2023.

When applying the disorderly transition scenario in the banks´ PD models using the FLESB framework, the worsening of companies' credit quality is generally more notable in those sectors most affected by the increase in the prices of CO2 emissions and fossil fuels, as these sectors exhibit more pronounced falls in their real GVA (Chart A.6). In addition, besides the effects on real GVA, the impact of the disorderly transition on the credit quality of the various sectors is also explained by the differences in their initial financial position and the varying sensitivity of their payment capacities to the general macroeconomic deterioration (Chart A.7).

Chart A.7

Differences in the average PD of loans to companies and the change in real GVA in the disorderly transition scenario

(y-axis: difference in average PDs over three years compared to the baseline scenario; x-axis: difference in average rates of change in GVA over three years compared to the baseline scenario)



Sources: AMCESFI biennial report on climate change risks to financial system (2023) and Banco de España.
Notes: Each point represents a sector. PDs are estimated for each bank, but differences in weighted averages are plotted for each sector. Weighting is done by number of holders. The five sectors with the highest impact on PD are: (1) manufacturing, (2) real estate development, (3) gas, steam and air conditioning supply, (4) cooking plants and (5) oil refining and electricity supply.

Other risk factors, balance sheet and income statement items were also projected consistently with the macroeconomic scenarios using the FLESB framework to estimate outputs in terms of banks' profitability and solvency. The impact on aggregate CET1 ratio of the banking sector would be - 1.2 pp at the end of the exercise, while the impact on profitability would be -0.7 pp. Although the aggregate solvency at the end of the exercise would be sufficient to comply with prudential regulatory requirements, the results show that the transition risks impact on the banking sector could be material.

2.2.2 Analysis of collateral for loans exposed to flood risk in Spain

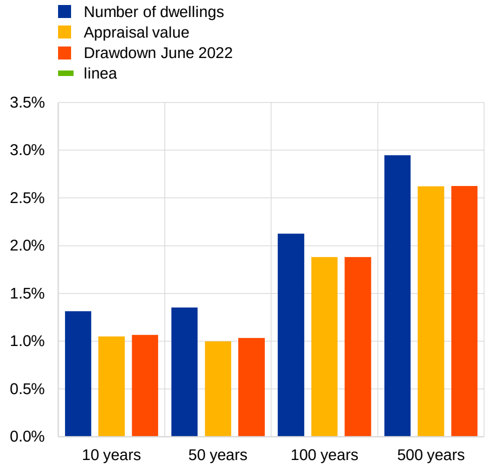
Banco de España has run a first exploratory exercise to identify buildings that serve as collateral for household loans in Spain located in potentially floodable areas. Combining data sources on flood-prone areas, with the Land Registry Database and information from the Central Credit Register (CCR) database of Banco de España, the studies identifies if a building that serves as collateral for loans is located in a floodable zone.

Initial results show that only 2.7% of the geolocated sample of dwellings acting as collateral for mortgages in June 2022 are located in flood zones with higher frequencies of events (10 and 50 years) (Chart A.8, panel b). If flood-prone areas with lower frequencies are also considered, a total of 7.7% of the sample of dwellings would be in areas potentially affected by floods. If the volume of credit drawn down or the appraisal value associated with them are considered, areas at risk of flooding would be limited to 6.6% in June 2022. Some caveats on the scope of this study should be noted, since, although an extensive geolocated sample of household mortgages is available, they are not calculated using all of them.

Chart A.8
Distribution and percentage of dwelling in flood-prone areas

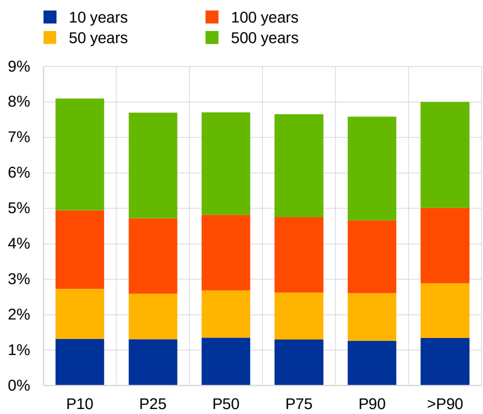
a) Distribution of dwellings with associated bank debt in CIRBE in flood-prone areas in each of the return periods

(y-axis: percentage)



b) Percentage of dwellings in flood-prone areas by LTV percentiles of all CIRBE mortgages

(y-axis: percentage)



Sources: AMCESFI biennial report on climate change risks to financial system (2023), Banco de España, Land Registry and MITECO.
Notes: Panel a: the sample corresponds to those loans granted to households registered in the CIRBE as at June 2022, the related collateral of which is a dwelling and whose land registry reference allows the geolocation to be obtained from the Land Registry (approximately 60% of this type of transaction). The Basque Country and Navarre are not included as their land registry information is not accessible. Panel b: The percentage is calculated in terms of number of transactions, but the conclusions are maintained using the appraisal values or the amounts drawn down as of June 2022. The LTV percentiles are calculated as the amount drawn down against the current loan (as of June 2022) over the value of the collateral associated with the loan. The sample corresponds to those loans granted to households registered in the CIRBE as at June 2022, the related collateral of which is a dwelling and whose land registry reference allows the geolocation to be obtained from the Land Registry (approximately 60% of this type of operation). The Basque Country and Navarre are not included as their land registry information is not accessible.

Regarding LTV distribution, it does not differ based on flood risk. Mortgage guarantees in flood-prone areas are not concentrated in any LTV percentile of the total sample of mortgage operations analysed. We obtain the percentiles of the LTV distribution in the mortgage transactions for which geolocation is available and calculate the percentage of housing guarantees which, within each section of this distribution, are located in areas classified as flood-prone. Chart A.8, panel a, shows that in all the tranches of the LTV distribution analysed there is a similar percentage of dwellings in flood-prone areas corresponding to the different frequencies of events.

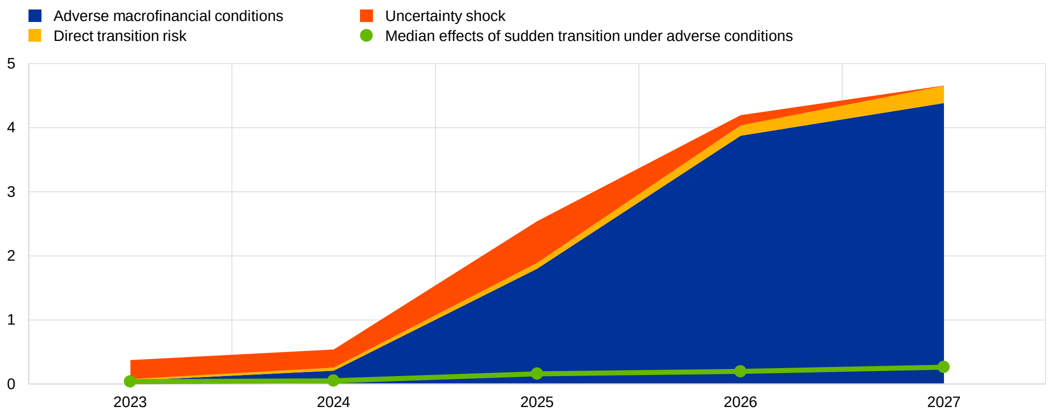
2.2.3 Application of adverse transition scenarios to credit risk assessment in the German banking sector

This box complements the euro area results (Section 3.3.2.1) with an application of the adverse transition scenarios to the German banking sector, using the Bundesbank's climate risk stress test framework to translate scenarios into credit risk metrics (see Gross et al. (forthcoming) and Frankovic et al. (2023)). The model is calibrated based on firm-level data for balance sheet indicators and carbon emissions. Country- and sector-level scenario variables are translated into firm-level effects using bridge equations and accounting identities. The key balance sheet indicators affected by transition scenarios are: profitability, liquidity, leverage, interest expenses and equity ratio. The model framework allows for a granular transmission of risks into banks' corporate loan portfolios.

Chart A.9

Impact of adverse transition scenarios on German banking sector credit risk:
Weighted average corporate loan portfolio probability of default, relative to baseline scenario

(y-axis: percentage points)



Source: Bundesbank.
Note: The chart shows the average corporate loan portfolio-level probability of default, weighted by the portfolio size of banks. Results for the sudden transition scenario based on the median instead of weighted average are depicted for comparison. The results shown in the figure are derived from the Bundesbank's banking sector climate risk stress test using the scenarios developed by the Project Team as input. See Gross et al. (forthcoming) and Frankovic et al. (2023) for further details.

The results suggest a sizeable increase in German banks' credit risk for the scenario of a sudden green transition under adverse macro-financial conditions (Chart A.9), consistent with the results for the euro area reported in Section 3.3.2.1. While the increase in average PDs is rather limited in the first two years, credit risk deteriorates substantially in years three to five of the scenario horizon. This is in line with the notion that risks from the transition, both direct and compounding ones, materialize rather sluggishly in firms' balance sheets. Transition risks related to the uncertainty shock are the main risk drivers in the first two years, while adverse macro-financial conditions become the key factor of credit risk increases afterwards. This is somewhat different to the results in Section 3.3.2.1, but may be explained by the relatively larger weight of financial market variables, notably equity prices, in the Bundesbank stress test model compared to the ECB framework. Financial market variables receive a comparatively high level of stress in the uncertainty shock scenario variant as a result of the increase in risk premia. If aggregate estimates for the sudden transition scenario based on weighted averages are compared with median effects, the latter are much lower (4.6% compared with 0.3%). This reflects the large degree of heterogeneity in credit risk effects across individual borrowers, as a number of high-emitting firms are more vulnerable towards transition risk shocks relative to the 'median' firm.

2.2.4 Banca d'Italia

Several studies carried out in the Bank of Italy assess the impact of transition risks via carbon taxes on the financial vulnerability of Italian households and firms.

A first study[22] simulates the increase in the number of vulnerable households and firms and the debt at risk associated with them because of the sudden increase in energy prices linked to the introduction of a hypothetical price on CO2 emissions for the Italian economy, in addition to what is already envisaged by the European Union Emissions Trading System (EU ETS). The increase is then passed to household income and to the EBITDA of firms, thereby obtaining the effects on the financial vulnerability of the two sectors, as defined in previous papers[23]. The results show significant heterogeneity in the expected effects. Using a counterfactual exercise, it is estimated that, using 2018 as the base year[24], the impacts on households would have been limited even with significant changes in prices, as in the case of a high price on CO2 (€200 and €800 per tonne). However, they would have been considerable for micro and small firms and for companies in the agricultural, manufacturing and real estate sectors, even with low carbon prices (€50 and €100 per tonne), and compatible with the energy price changes recorded for 2021. A second study[25] extends the approach described and estimates the default rates (sectoral) of loans to firms from

[22] I. Faiella, L. Lavecchia, V. Michelangeli and A. Mistretta, 'A climate stress test on the financial vulnerability of Italian households and firms', Journal of Policy Modeling, 2021, also published as Banca d'Italia, Questioni di Economia e Finanza (Occasional Papers), 639, 2021.

[23] C.A. Attinà, F. Franceschi and V. Michelangeli, 'Modelling households' financial vulnerability with consumer credit and mortgage renegotiations', International Journal of Microsimulation, 13, 2020, pp. 152-173, also published in Banca d'Italia, Questioni di Economia e Finanza (Occasional Papers), 531, 2019; A. De Socio and V. Michelangeli, 'A model to assess the financial vulnerability of Italian firms', Jo urnal of Policy Modeling, 39, 2017, pp. 147-168, also published as 'Modelling Italian firms' financial vulnerability', Banca d'Italia, Questioni di Economia e Finanza, 293, 2015 (Occasional Papers), 293, 2015.

[24] The year 2018 is used in the research paper that introduced the microsimulation model for the energy demand of Italian households and was kept to help in comparing the results (see I. Faiella and L. Lavecchia, 'Households' energy demand and the effects of carbon pricing in Italy', Banca d'Italia, Questioni di Economia e Finanza (Occasional Papers), 614, 2021).

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

Italian banks according to the share of financially vulnerable firms and to their debt. The analysis shows that, if every ton of CO_2 emitted had been penalized with a carbon price of €50 in 2018, the average quarterly default rate for loans to firms would have increased the following year by about one fourth (from 2.8 to 3.6 per cent), though remaining below the historical average observed in the years 2006-2019. The estimates obtained reflect the relatively solid financial structure of firms and the low default rates recorded in 2018. The effect would have been greater and varied across sectors with a tax of €800, the highest value in a 'disorderly' transition scenario as defined by the NGFS. Introducing carbon pricing in periods of greater vulnerability for firms or with higher default rates could therefore have a more significant impact.

Finally, a recent study[26] extends the above analyses to firm-level PD information using the in-house credit assessment system of the Bank of Italy: it estimates the impact of a change in energy expenditure on Italian firms' credit risk, measured as the 12-month default probability (PD), examining a shock to energy expenditure originating from different levels of a carbon tax.

2.2.5 Drought and heat risk scenario-based vulnerability assessment in Spain

Banco de España has assessed the impact of shocks in line with the ECB-ESRB drought and heat risk scenario[27] on the Spanish banking sector. This scenario includes one-year shocks to sectoral real gross value added, with stronger impacts on those activities in which workers are more exposed to climate, such as the construction sector and agriculture. The study of their implications is of particular relevance for the Spanish banking sector, given that the shocks on real GVA estimated for European countries would be more pronounced in southern European countries.

To run its climate change stress test, Banco de España has completed and extended the set of variables needed for the exercise. The full scenario considers a three-year horizon, the first of which incorporates the climate shock of droughts and heatwaves, which would result in a real GDP impact of -1.3 pp and an increase of 1.5 pp in inflation with respect to the baseline scenario, and two additional years in which the scenario reverts to trend growth rates.

As was the case for the transition risk analysis, the stress testing methodology used to estimate the impact of this scenario on the Spanish banking sector was the Banco de España's FLESB framework (Chart A.10). As expected, the results showed that the deterioration in credit quality would be higher in the sectors most affected by the fall in productivity (within the real estate sector, forestry, logging, transport and related activities) with increases in their probabilities of default (PD) of between 0.5 pp and 1 pp compared to the baseline scenario.

[26] Di Virgilio S., Faiella I., Mistretta A., Narizzano S, 'Assessing credit risk sensitivity to climate and energy shocks', Banca d'Italia series 'Markets, infrastructures, payment systems', September 2023

[27] The narrative of this scenario can be found under section 3.1 of the **Macro-financial scenarios for the 2022 climate risk stress test**. This scenario is based on NGFS estimates for labor productivity shocks due to heat stress.

Chart A.10

Impacts of the ECB-ESRB (2022) drought and heat risk scenario on the Spanish banking sector

a) Impact on sectoral GVA

(y-axis: percentage points)

b) Differences in PD of loans to companies and change in real GVA

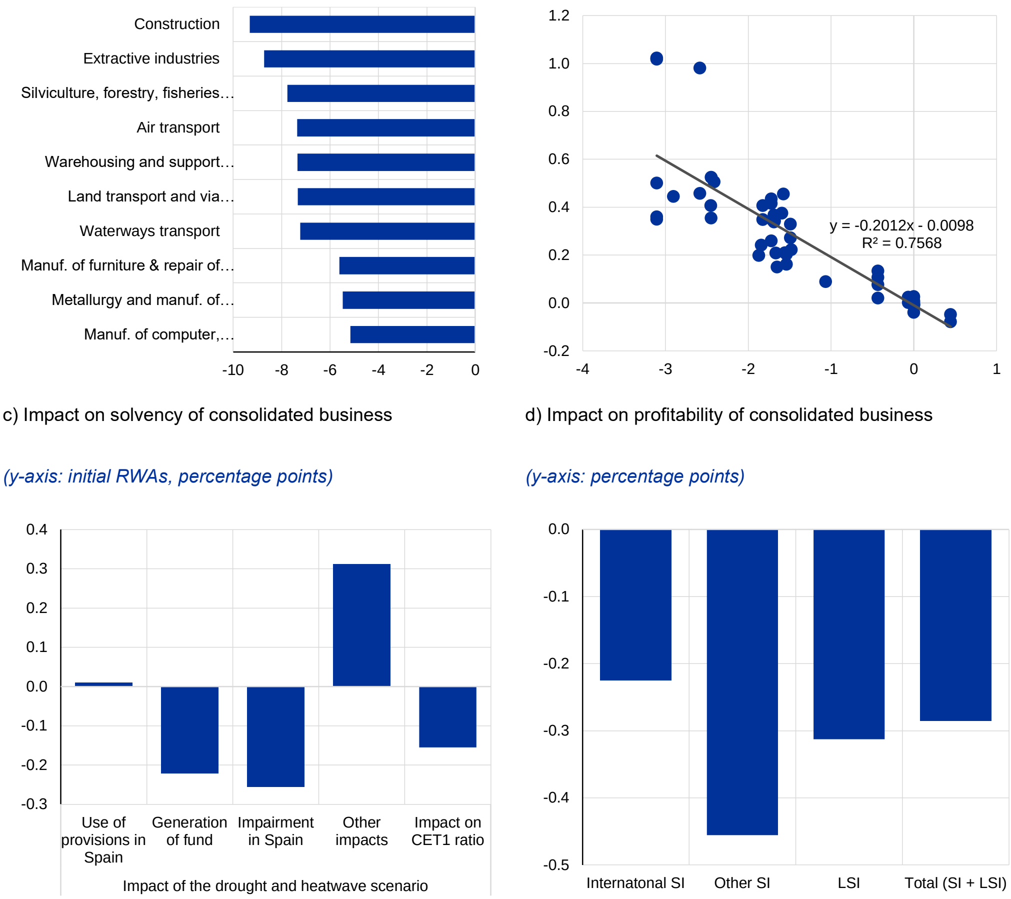
(y-axis: difference in average PDs over three years compared to the baseline scenario; x-axis: difference in average rates of change in GVA over three years compared to the baseline scenario)

c) Impact on solvency of consolidated business

(y-axis: initial RWAs, percentage points)

d) Impact on profitability of consolidated business

(y-axis: percentage points)



Source: AMCESFI Biennial Report on Climate Change risks to Financial System 2023 and Banco de España.
Notes: Panel a: impacts are defined as the differences with respect to a trend baseline scenario in growth rates at the one-year horizon (t+1). Panel b: each point on the graph represents a sector. PDs are estimated for each bank, but differences in weighted averages are plotted for each sector. Weighting is by number of holders. The differences compared to the baseline scenario are presented. The five sectors with the highest impact on PD are shown in pink. Panel c: the impact on solvency is defined as the changes in the expected three-year CET1 ratio and different financial flows over the three years of the exercise (e.g. generation of funds) that would result from the materialisation of the drought and heatwave scenario compared to the baseline scenario. The generation of loss absorption funds is determined by the operating margin in Spain, including also the net result obtained abroad for those institutions with significant international activity. Since the impact on international activity is not modelled, the net result abroad in the drought and heatwave scenario does not vary with respect to the base scenario. Financial impairment losses on loans and foreclosed assets in the Spanish business. The impact on capital of the potential impairment of sovereign exposures at the consolidated level is not significant due to the absence of financial stress assumed for this portfolio. Other consolidated gains and losses, tax and exchange rate effects, distribution of profit, coverage of losses on ICO-backed loans by the State and change in RWAs. Panel d: the impacts on profitability are defined as variations in the ratio of profits after tax to RWAs compared to the base scenario.

At the end of the three-year horizon, the aggregate CET1 ratio consumption of the banking sector would be somewhat less than 0.2 percentage points (pp) with respect to the baseline scenario. Capital consumption is mainly explained in the stress exercise by higher impairment losses and lower net margin generation in the Spanish business. Regarding profitability, the impact would be 0.3 pp on initial RWAs. This aggregate impact is moderate on the profitability and solvency of the Spanish banks, since the drought shock has a limited effect at macroeconomic level. Nevertheless, the study of the impact channels identified is relevant for assessing the potential vulnerabilities of the banking sector to a higher degree of materialisation of this type of climate risk, and the recurrence of droughts and heatwaves could increase their negative impact with respect to what is estimated in this short-term exercise.

2.2.6 Floods and financial stability: Evidence from the Netherlands

De Nederlandsche Bank (DNB) is increasingly using scenario analysis to assess the impact of floods on financial stability. So far, the focus has been on banks' exposures to real estate, given that flood-related property damages would not necessarily be covered by current insurance policies.

A first analysis (Caloia and Jansen, 2021) started from a standard banking stress test approach and then considered six flood scenarios of increasing severity. These six flood scenarios differed along two dimensions. First, whether the affected part of the Netherlands was protected from floods and, second, the severity of the floods. In this analysis, flood severity was measured as three distinct levels of inundation depth.

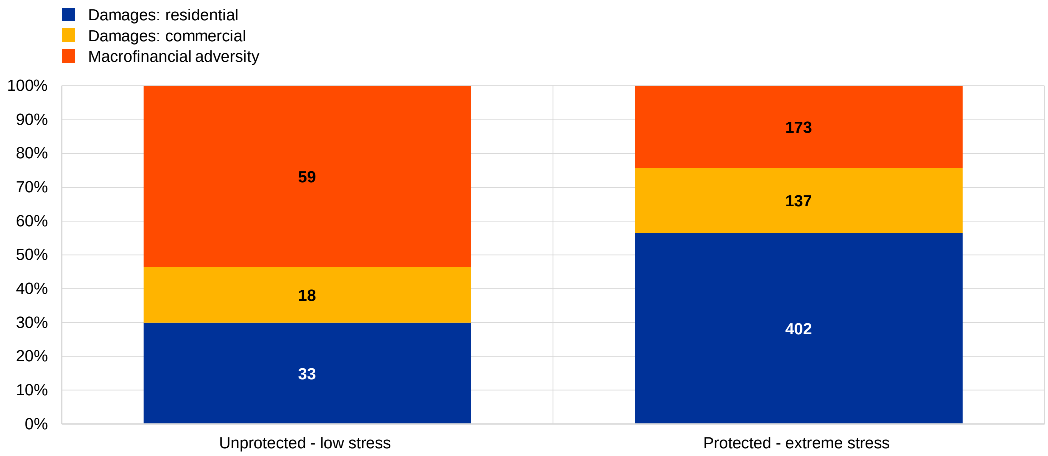
Based on the degree of inundation depth, the analysis used a set of standard damage function to compute the property damages (in euro amounts) that would be associated with the various flood scenarios. In addition to property damages, the analysis also considered macro-financial adversity, for instance whether a flood would trigger a recession. Based on the combination of property damages and macro-financial shocks, the analysis considered implications for banks' capital positions.

Chart A.11 below gives an indication of the relative importance of three drivers of system-wide capital depletion in the least severe (left bar) and most severe (right bar) flood scenario. These drivers are losses due to property damages (either residential or commercial real estate) or macro-financial shocks. For the least disruptive flood scenario, the combination of macro-financial shocks was found to be most relevant, as it was behind 54% of the system-wide capital depletion. As the scenario severity increases, the relative contribution of the property damages become more important. As the second bar indicates, in the most extreme case, the property damages would be behind more than 75% of the overall capital depletion. This large impact reflects the strong increase in credit losses and loan riskiness for banks, given that the flood damages would lead to a large decline in collateral values.

Chart A.11

Key drivers of losses – damages to residential or commercial real estate and macro-financial shocks – across the two flood scenarios

(y-axis: percentage)



The analysis in Caloia and Jansen (2021) was, in essence, a reverse stress test. To understand the channels through which floods could impact financial stability, a wide range of inundation depths and macro-financial shocks was taken into consideration. Building on this approach, on-going work at de Nederlandsche Bank is focusing on refining the analysis. For instance, the granularity of flood scenarios can be improved by making more specific which parts of the Netherlands would be inundated and to which degree.

3 Annex – Supplementary material on the Policy considerations

3.1 Lessons from the use of SyRB for systemic risks

The application of the SyRB to climate risks can benefit from the experience gained by jurisdictions from its current use for other systemic risks. Over the past decade, the SyRB has been implemented by 21 macroprudential or designated authorities within the European Economic Area (EEA). SyRB implementations have targeted multiple structural risks across various categories or sectoral risks associated specifically with real estate exposures[28]. However, there is no existing example of a single designated authority setting multiple SyRB requirements to address distinct risks within a particular jurisdiction, that could serve as an example for the use of a SyRB addressing climate risks in addition to an existing SyRB that covers other types of systemic risks.

The implementation of a general SyRB for climate risks typically relies on monitoring of a set of risk indicators, including in particular measures of concentration risks. The decision to activate and the concrete implementation of a general SyRB by national authorities are generally informed by the monitoring of relevant risk indicators. As discussed in Chapter 1, numerous indicators have been developed in recent years for quantifying climate risk. Despite the ongoing data quality issues, these indicators can already be utilized by national authorities to monitor risk developments and assess the need to implement a general SyRB. Indicators measuring risk concentration could play a particularly significant role in this context, given the role that such indicators play already in the implementation of a general SyRB in numerous EEA jurisdictions: Austria (AT) which includes measures of concentration above defined thresholds, such as exposures and earnings of Central, Eastern, and South-Eastern European countries in relation to banks' total assets and total earnings; Estonia (EE) identifies concentration of exposures to exporting firms as a source of systemic risk; Iceland (IS) recognizes the sectoral concentration of exporting activities (fish, aluminium, tourism) as posing systemic risks; Finland (FI) employs indicators that measure the sector and industry specific relative shares in credit portfolios to assess structural vulnerabilities in its banking system; Norway (NO) includes indicators on the concentration of credit institutions' lending to the corporate sector by sector breakdown and identifies concentration of lending secured by real estate as a structural risk (more on this in Section 5.3 in the **ESRB Final report on the use of structural macroprudential instruments in the EU**). A general SyRB for climate risks could be activated based on bank-specific concentration indicators, which are particularly suitable for discouraging excessive build-up of climate risk within individual banks. (For further details, refer to Section**Error! Reference source not found.**).

Sectoral SyRB implementations have, so far, covered exposures secured by real estate. In BE, DE, LI, LT, MT and SI the SyRB has been in place with a limited sectoral coverage exclusively consisting of exposures secured by real estate. Other Member States, such as FI, may also include the risk assessment of housing loans and other real estate investment, beside other structural risks.

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[28] Some of these risk targets, namely those which covered risks related to systemically important institutions, have been explicitly ruled out after the CRDV revision, but they are arguably less relevant for the discussion on CRFR mitigation.

All of these Member States have included in the geographical scope the entire jurisdiction. Conceptually, the relevance of these sSyRB applications is limited as current sectoral dimensions do not recognize climate risk characteristics and could only poorly approximate the geographical and economic activity-based segmentation that might be needed to cover climate risk exposures. Nonetheless, SyRB applications that cover exclusively sectoral risks could be instructive for the design and application of a potential SyRB for climate risk. (see Section **Error! Reference source not found.**).

3.2 Potential activation indicators for borrower-based measures accounting for climate risks

Table A.2

Potential activation indicators for borrower-based measures accounting for climate risks

Indicator category[29]	Potential indicators on CRFRs	Implementability
Real estate (RE) overvaluation (general or with regional concentration)	Overvaluation models incorporating RE sustainability characteristics	Implementable depending on model developments and data availability
	Deviations from their long-term averages of the price-to-income ratio in a transition risk or physical risk scenario	Implementable using existing climate stress-test
	Risk premium on loans financing RE assets exposed to climate risk, price premium on RE assets protected from climate risk	Implementable conditional on access to granular physical risk data, energy expenditure data and energy certificates data or estimates
	Share of RE collateral located in elevated physical risk areas, or with low energy efficiency scores	Implementable conditional on access to granular physical risk data, and energy certificates data or estimates
Borrower debt servicing capacity	Households emissions per m2, by income (and potentially sector of activity)	Implementable
	Share of energy expenditure in household net income by income bracket	Implementable using for instance Household Budget Survey
	Share of energy expenditure in household net income per energy efficiency category of the RE asset	Implementable conditional on energy certificate data availability or estimates
	Share of energy expenditure in NFC revenue by firm size, and by energy efficiency category of the RE asset	Implementable conditional on energy certificate data availability or estimates
	NFC exposure to transition risk (Weighted avg. carbon intensity: WACI, relative to revenue; Carbon footprint: relative to assets, Carbon tilt: carbon financing vs. carbon in GVA…)	Implementable
Observed distribution of DSTI/DTI/LTV	CRFR sensitivity of the borrowers effectively limited or near the right tail of the observed DSTI/DTI distribution or near a DSTI/DTI limit in place	Implementable conditional on access to granular physical risk data, energy expenditure data and energy certificates data or estimates, and link between credit data and climate data.
	Sustainability characteristics of the RE collateral of loans near the right tail of the observed LTV distribution or near an LTV limit in place	

29 Based on the type of indicators currently used.

4 Annex – Supplementary material on nature risks

4.1 Key concepts needed to identify nature-related financial risks

The overview is based on internationally acknowledged definitions, including those stemming from the IPBES, the CBD, the EEA and the NGFS.

- Natural capital: the stock of renewable and non-renewable natural resources, encompassing all abiotic (i.e. the physical and chemical environment such as temperature, water, natural minerals or solar energy) and biotic (i.e. the living biological components of ecosystems such as plants animals and microorganisms) stocks that deliver a flow of goods and services that can be used by people.

- Nature: While it is difficult to define nature, to illustrate its meaning we refer to the IPBES Conceptual Framework: "The natural world with an emphasis on the diversity of living organisms and their interactions among themselves and with their environment." The NGFS follows this definition, highlighting that a key consideration is that the term 'nature' captures both the biotic (living) and abiotic (non-living) elements of our planet, including biodiversity but also climate.

- Ecosystems: the community of living organisms, such as plants, animals, microbes and fungi, in conjunction with the non-living components of their environment, such as energy, air, water and mineral soil, all interacting as a system (e.g. forest or marine ecosystems) (IPBES).

- Ecosystem services: realised flow of goods and services provided by ecosystems for which there is demand (e.g. nutrition, clean air), thereby benefitting economic and other human activities. They, at least to some extent, mirror the state of the environment and ecosystem functioning. The Common International Classification of Ecosystem Services (CICES), developed for environmental accounting, distinguishes between three main ecosystem services categories:

  - provisioning services (abiotic; biotic) - biotic services refer to e.g., cultivated plants used for alimentation, food crops, materials from animals of use to humans; abiotic services refer to e.g., hydropower or the use of underground heat.

  - regulating and maintenance services (abiotic; biotic) - biotic services refer to e.g., the decomposition or filtering of waste, human-induced plan pollination or pest controls; abiotic services refer to e.g., physical barriers to landslides or flows

  - cultural services (abiotic; biotic) - biotic services refer to e.g., elements in nature humans consider important to preserve for future generations, leveraging nature for recreation activities; abiotic services refer to e.g., elements in the physical environment humans can study, or those that we consider important to preserve for future generations.

- Pressures on ecosystem services: The main pressures that drive a reduction in ecosystem services are climate change impacts, sea land-use change, habitat loss or over-exploitation, invasive species and pollution. Therefore, measuring the stocks and flows of ecosystem services over time can provide an indication of the well-functioning of ecosystems.

- Biodiversity: the variety of all life on earth, the variability among living organisms from all sources, including inter alia terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, referring to the diversity within species (genetic diversity), between species (specific diversity) and of ecosystems (ecological diversity). Biodiversity underpins the ability of the natural world to generate flows of ecosystem services and contributes to the resilience of ecosystem services to recover from shocks. Hence, the loss of biodiversity is likely to create nature-related risks.

- Biodiversity loss: the reduction of any aspect of biological diversity that results from loss in a particular area through death (including extinction), destruction, or manual removal. It adversely affects human-environment connections and diminishes the provision of ecosystem services, with negative economic impacts on individuals, households, organisation and countries.

4.2 Challenges in the way of conducting a scenario analysis

At the current juncture, there are three main challenges in the way of conducting such a scenario analysis. First (step 1 in Figure 4 of the main report), we need to a have clear idea of the type of hazards or shocks that could occur, but these remain uncertain and no ad hoc scenarios have yet been designed for central banks and financial supervisors (unlike for CRFRs, with the recent development of climate-related scenarios (see NGFS, 2020)). As a result, both physical and transition sources of risks remain extremely difficult to envision in a systematic manner. Moreover, the multiplicity of metrics relating to biodiversity - among others the difficulty of translating them into a single monetary metric such as a universal price on carbon - makes it extremely difficult to design a comprehensive scenario narrative. This poses a challenge when trying to determine how the global loss of biodiversity can impact GDP or how the measures aimed at protecting biodiversity can impact several economic sectors through pricing mechanisms.

Second (step 2 in Figure 4 of the main report), once the scenario of hazard or shock is defined, we need to assess the exposure of agents (whether it be individuals, businesses, financial institutions or sovereigns) to this transition or physical shock. One can define exposure as being in places and settings that could be adversely affected by the hazard. For example, in the case of a policy shock consisting of the extension of protected areas, the exposure of a given business to this shock depends on whether it has production facilities or suppliers located in the future protected area. However, estimating the exposure of specific agents remains difficult without a clear idea of the hazard and could require highly granular data, such as geolocation data.

Third (step 3 in Figure 4 of the main report), we need to understand the risk (sensitivity) that results from a given hazard and a given exposure, as exposure to the hazard does not automatically translate into risk. Indeed, once exposed, it is necessary to evaluate agents' sensitivity to the shock i.e. their propensity to incur losses or be impacted by the shock once exposed -, and their adaptive capacity – i.e. the ability to cope with these impacts or losses. In our example above, the business will be more sensitive if most of its production facilities are located in future protected areas (which may lead the company to lose a significant proportion of its turnover and its physical assets). However, it may be able to adapt to the shock and reduce losses if its production facilities can be easily moved out of the protected area, or if the company can transform its activity and shift towards a sector that is less damaging to biodiversity.

In order to conduct a nature-related scenario analysis, we need to better grasp the economic consequences of biodiversity loss. For this, it is necessary to understand how ecosystems work and how they interact with the economic system. A major difficulty lies in the complexity of the processes at work (Kedward et al., 2020), which the models and approaches described in the previous section fail to tackle adequately. One aspect of this complexity is that, unlike in the case of climate change, where a common measurement unit such as ton of CO2 equivalent can be used to summarise effects, "it is illusory to hope that biodiversity might be described using a single indicator" (Chevassus-au-Louis et al., 2009).

The non-linearity of nature degradation and the high uncertainty associated with it pose another challenge to the quantification of its economic impact. While there is consensus that crossing critical ecological thresholds may lead to catastrophic and irreversible results, it is hard to predict exactly where these tipping points lie (Hillebrand et al., 2020). Dasgupta (2021) emphasises that these dynamics could give rise to "green swans", i.e. potentially systemically important financial risks triggered by socioecological dynamics (Bolton et al., 2020a and 2020b; Svartzman et al., 2020).

Another challenge when assessing biodiversity-to-economy linkages concerns the substitutability of ecosystem services. Most biodiversity/economy models do not factor in the non-substitutability of natural capital and take a "weak sustainability" approach (Dietz and Neumayer, 2007). In this approach, all that matters is whether overall capital - measured in monetary terms - increases. Loss of natural capital is significant only insofar as it threatens the accumulation of physical and human capital. Conversely, under a "strong sustainability" approach (Dietz and Neumayer, 2007), an increase in manufactured or human capital cannot – or can only very partially – replenish existing stocks of natural capital. Put another way, the depletion of natural capital and ecosystem services in a world where biodiversity is collapsing cannot be offset by increased revenue, or if so, only to a very limited degree: "If the biosphere was to be destroyed, life would cease to exist" (Dasgupta, 2021).

4.2.1 The role of narratives in building a scenario analysis

As explained above, the first step to developing a scenario for a forward-looking risk assessment is to have an idea of the type of hazards or shocks that could occur, i.e. of the narratives that inform such a scenario. However, biodiversity hazards, objectives and policies are very diverse, making it challenging to develop a comprehensive and consistent scenario for either physical or transition risks.

The development of nature-related narratives faces what could be called a "local-global trade-off": granularity is even more important than for climate scenarios, but it comes at the expense of having off-the-shelf global scenarios, whereas global scenarios are likely to miss the granularity needed to properly appreciate nature-related issues. For instance, for physical risks, local granularity and specificity are important for accurate modelling, but it would rapidly become impossible to enumerate the multiple physical hazards that could occur in a multitude of ecosystems. For transition risks, staying within planetary boundaries requires decisive changes related to many pressures on nature and biodiversity – e.g. regarding land-use policies and conservation programs, direct exploitation of ecosystems and greenhouse gas emissions – that will be difficult to translate into the multiple policies needed at the local level.

In order to overcome this "local-global trade-off", the NGFS proposes different approaches that could serve as starting point to assess nature-related financial risks (NGFS, 2023):

For physical risks, they suggest using two frameworks, namely ESGAP and INCAF-Oxford. ESGAP (Environmental Sustainability Gap) is an index of environmental health that downscales the concept of planetary boundaries to the national level. It can help identify which ecosystems and associated environmental functions are the most degraded – and thus more likely to collapse – through aggregated metrics that help to identify the distance between the current state of an ecosystem and a "good" operating state of that ecosystem. The INCAF-Oxford framework is a complementary approach that centers on the potential hazards themselves. It is based on an extensive scientific review of potential hazards (i.e, shocks) coupled with relevant datasets. The hazards are mapped backwards - to the ecosystem services disrupted, and drivers of ecosystem degradation along the impact chain- and forwards – to the primary economic impacts. This method allows for a translation of hazards into specific "shocks" to be assessed.

For transition risks, they review existing nature-related frameworks covering a wide array of potential policies, from which transition-related hazards can be better identified. They then suggest a two-step approach to generate narratives. The first step is to identify through simple, non-aggregated metrics how different sectors in different countries could be impacted by some of the key policies that could emerge from existing frameworks. The second step is to provide central banks and supervisors with some guidance through which they could better calibrate such hazards to their own economy. The NGFS acknowledges, however, that they only provide initial suggestions and that these approaches would require more work to be used for a fully-fledged risk assessment.

4.3 Models, methods and data

The relevance of nature-related financial risk assessments for supervisors and central banks requires reliable measurements and valuation techniques. Although there already exist both qualitative and quantitative data and metrics, further developments are needed. This data could help policymakers better understand the potential impact that nature degradation can have on the economy. At the same time, measurements of the impact of the economic activity on nature could make possible the assessment of policies aimed at reducing our biodiversity footprint.

While fully developed measurements of nature-related financial risk are still missing, there has been a proliferation of metrics and indicators used to assess impacts and dependencies in the financial system as showcased in section 1.2. The availability and quality of reliable measurements and valuation techniques for nature-related financial risk has become increasingly important as a growing number of central banks and supervisors have started considering the issue.

Nature-related risks are characterized by a high degree of multidimensionality. Furthermore, a good understanding of how ecosystems function is necessary to fully map the impact and dependencies of nature on economic activities[30]. This multidimensionality is further complicated by the presence of possible non-linearities and correlations among ecosystems. Multiple indicators and approaches are generally necessary to characterize ecosystems intrinsically (e.g., for their complexity, diversity, cultural significance and wilderness). Despite this high degree of complexity, numerous measurements of dependency and impacts on nature have started to become available. A review of selected measures is provided below.

4.3.1 Available datasets – impacts and dependencies

Dependency Assessment Measures

ENCORE

ENCORE focuses on goods and services that nature provides to enable economic production and on the possible impacts that economic activity might have on nature. It maps 86 production processes based on the Global Industrial Classification Standard (GICS) with 21 ecosystem services. In turn, the ecosystem services are related to 8 natural assets. For a given ecosystem service, ENCORE attributes a materiality score ranging from Very Low to Very High in a 5-step discrete classification. These scores were obtained from a literature review of the relevant research.

ENCORE does not provide location specific information. Moreover, the dataset provides only direct dependencies which do not consider suppliers and their possible changes

[30] See https://publications.banque-france.fr/en/silent-spring-financial-system-exploring-biodiversity-related-financial-risks-france

caused by the depletion of nature assets. Therefore, the ENCORE dataset should be considered as a general guideline to assess the direct dependency and impact of economic activities on nature.

INCA platform

The main aim of INCA is to develop ecosystem accounts at the EU level using a systematic approach that is in line with the official statistical standard of ecosystem accounting, which is the System of Environmental-Economic Accounting (SEEA). Specifically, the INCA platform provides geographical datasets for 7 ecosystem services: crop provision, timber provision, carbon sequestration, crop pollination, wood provision, water purification, flood control, soil retention and species maintenance. The maps cover the years 2000, 2006, 2012, and 2018 and EU-27 member states.

Using an ecosystem service potential and its demand, INCA determines the actual flow (use) of an ecosystem service. These flows are then reported in Supply and Use tables. When the potential does not match the demand, then an ecosystem service mismatch is accounted. These discrepancies are key to assess vulnerabilities in ecosystem services.

WWF Biodiversity Risk Filter

The WWF Biodiversity Risk Filter is an open access web-based tool that can be used by business and financial institutions to map their biodiversity-related risks. The tool provides a sectoral assessment of the dependencies and impacts on biodiversity for 25 industrial sectors using a broad set of 33 biodiversity risk indicators (20 indicators of industry dependency and 13 of industry impacts). The WWF Risk Filter employs 56 underlying biodiversity datasets to produce an industry materiality table that assigns a dependency or impact rating to each industry and biodiversity indicator, resulting in a matrix of 825 risk ratings. The rating is performed in a 0 to 5 scale; an industry materiality of 5 indicates very high dependency/impact, whereas a materiality of 0 shows no dependency/impact.

In additional to sectoral granularity, the WWF Risk Filter provides spatial maps of biodiversity importance and integrity that can be used to assess biodiversity risk in specific business locations or supply chain sites. The local state of biodiversity is based on the 56 biodiversity datasets that are used to construct the risk indicators. WWF risk filter users can introduce the location of business assets and supply chain sites and obtain tailored risk ratings for each geographical location. Regarding water risk, the WWF risk filter also provides a country-level assessment of physical, regulatory, and reputational risk for a sample of 251 countries.

Overall, the WWF risk filter can be used to obtain a biodiversity risk assessment based on the location of company sites, their industry classification, and the local state of biodiversity, providing a comprehensive tool that jointly considers dependencies and impacts, and incorporates both sectoral and geographical information.

Copernicus

Copernicus is the European Union's Earth observation programme and provides information through six thematic services: land, marine, atmosphere, climate change, emergency management and security. All information is free and openly accessible to all users.

- The Copernicus Land Monitoring Service (CLMS) produces a set of biophysical variables that depict the state and evolution of the vegetation, the energy budget, the water cycle and the cryosphere over the land surface at global scale and throughout long-term time series.
- The Copernicus Marine Service provides data on the state of the Blue (physical), White (sea ice) and Green (biogeochemical) ocean, on a global and regional scale.
- The Copernicus Atmosphere Monitoring Service (CAMS) provides daily information on the global atmospheric composition. To do so, it monitors and forecasts variables such as greenhouse gases (carbon dioxide and methane), reactive gases (e.g. carbon monoxide, oxidised nitrogen compounds, sulphur dioxide), ozone and aerosols.
- The Copernicus Climate Change Service provides access to high-quality climate data through the Climate Data Store (CDS). The CDS contains a variety of climate datasets and a cloud interface to visualise them. Finally, CDS provide real world applications of its data and tools.
- The Copernicus Emergency Management Service (CEMS) provides geospatial information on management of natural disasters, man-made emergency situations, and humanitarian crises.
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Table A.3
Dependency of economic activities to ecosystem services

Data source	Key features					Pros and cons
	Confident.	**Accessibility**	**Granularity**	**Scope**	**Time coverage**	
ENCORE	Non confidential	Open source	157 sectors, no country-specific	21 services, global	Not applicable	+ coverage and scope - Not geographic-specific
INCA platform	Non confidential	Open source	Various geospatial granularity (mostly NUTs3)	9 services (SUT), EU	2000-2018	+ high frequency - Few eco services and sectors covered
WWF Risk Filter Suite	Non confidential	Open-source map	25 sectors, global watersheds grid	56 global biodiversity data sets	Not applicable	+ large collection of risk index - not immediately available for download
Copernicus	Non confidential	Open-source map	Global coverage at different resolutions	Around 20 indexes	Varies across index	

Impact Assessment Measures

GLOBIO

The GLOBIO model is a global model of biodiversity intactness, expressed by the mean species abundance (MSA) metric, as a function of multiple anthropogenic pressures on the environment (Schipper et al., 2019; Alkemade et al., 2009). Mathematically, the GLOBIO model represents a set of quantitative relationships that assess the impacts of anthropogenic pressures on biodiversity. The pressures included in the GLOBIO model are as follows: climate change (expressed in terms of GHG emissions), land use change, road disturbance, atmospheric nitrogen decomposition, mining and habitat fragmentation. The MSA metric is quantified based on changes in community composition in relation to each environmental pressure. MSA values are calculated by dividing the abundance of each species found in relation to a given pressure level by its abundance found in an undisturbed situation, truncating the values at 1, and then calculating the arithmetic mean over all species present in the reference situation (Alkemade et al., 2009; Schipper, Bakkenes, et al., 2016). The GLOBIO model integrates the pressure–impact relationships with spatially resolved data on the pressures, resulting in high-resolution spatial maps with impact-specific MSA values.

The GLOBIO model is especially appropriate for scenario-based modelling, which is a powerful approach to evaluate how possible future socio-economic developments may affect biodiversity. GLOBIO can also be used to quantify various policy relevant dimensions behind human-nature interactions, such as impacts of human activities on biodiversity and ecosystem services, the effectiveness of large-scale policy options for conserving biodiversity and ecosystem services, production and consumption-based biodiversity impacts (footprints), and benefits that people can obtain from nature (i.e., nature's contribution to people or nature based solutions). Nevertheless, MSA presents some limitations. First, it represents only a measure of biodiversity intactness and thus does not necessarily capture all the multitude of ecosystem services that nature might provide. In addition, it is inherently difficult to immediately grasp. MSA is computed in relation to an "undisturbed' habitat which can be difficult to visualize.

EEA indicators

EEA indicators support the policy making process in all the stages, providing data to design policy frameworks and to evaluate them over time. EEA indicators provide time series on topics ranging from agriculture, biodiversity - ecosystems, air pollution, climate change mitigation and adaptation, environment and health and energy to transportation. They assess whether associated policies objectives have been met and if those are likely to be achieved by the given deadlines. They can also enable assessments on where and how it is necessary to intervene to achieve these targets.

Table A.4
Impact of economic activities on ecosystem services[31]

Data source	Key features					Pros and cons
	Confident.	**Accessib.**	**Granularity**	**Scope**	**Time coverage**	
GLOBIO	Non confidential	Open source	Global, highly granular (around 300x300 m)	Focus on land use and MSA only	2015 and three scenario data for 2050	+ well established in the literature - Scope
WISE – status of water	Non confidential	Open source	Minimum EU 27, often EEA countries	Several indicators on surface and ground water	2010-2019	+ very specific on status of water - Scope
FISE – forest indicator	Non confidential	Open source	EEA countries	Basic and derived indexes	Various coverage	+ detail representation of EU forest - usually at a country level
SEBI indicator	Non confidential	Open source	EU	14 indicators	Various coverage (in general from 2010-2019)	+ secured legitimacy and robust approach - usually at a country level
EEA indicators	Non confidential	Open source	EU	Around 158 indicators	Various coverage	+ the indicators cover multiple services

Supply Chain Data

Nature represents a global and systemic risk. Therefore - like with climate risk - it is important to assess the dependency and the impact not only of a firm in isolation, but also of its supplier. Because of that it is important to have granular and precise data of the supply chain composition of firms. When firm-specific supply chain data is not available, it is possible to use sector/country aggregation.

Multi-Regional Input Output (MRIO) tables map the sale and purchase relationships between suppliers and consumers across economies. These tables can be used to determine the value chains of each economic sector in a given region using information on the value of total output produced and the value of intermediate goods used to produce this output. Furthermore, the MRIO tables can contain information on environmental pressures stemming from both production and consumption of the goods and services considered. These tables are called environmentally extended multi-regional input–output table (EE-MRIO), see section 1.3.2.

[31] For more information on WISE, FISE, and SEBI, please refer to Box 6.

EXIOBASE

EXIOBASE is a global Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT).[32] The dataset is the result of harmonization of different SUTs and IOTs of different countries, developed by a consortium of several research institutes. EXIOBASE provides two input-output table formats: monetary and hybrid IOT. The former ranges from 1995 to a recent year for 44 countries (28 EU member plus 16 major economies) and five rest of the world regions. Data is provided for 163 industries and 200 products, and it is extended with 417 emission categories and 662 material and resources categories. On the other hand, the hybrid version is available only for the year 2011. The term hybrid indicates that the dataset is extended with physical flows of materials and energy, not only monetary exchanges.

EORA MRIO

The Eora global supply chain database consists of a multi-region input-output table (MRIO).[33] Compared to other datasets, Eora accounts for 190 countries and 15,909 and spans from 1990 to 2021. The IOTs are then expanded extended with 2720 environmental indicators covering GHG emissions, labour inputs, air pollution, energy use, water requirements, land occupation, N and P emissions, and primary inputs to agriculture. The data is available in two main formats: a high-resolution version (full Eora) which preserve all national IO tables detail, and a simplified version (Eora26) that aggregates the different national classification in 26-sector harmonized classification.

OECD-IOTs and FIGARO

Both OECD-IOTs and FIGARO are standard inter-country supply-use and input-output tables. **Compared to the previous datasets, they do not currently include environmental extensions. They can nonetheless provide useful information on supply chain structures**. The OECD-IOTs presents matrices of 45 inter-industrial flows of good and services in current prices for 66 countries, covering the years 1995 to 2018.FIGARO considers 65 sectors/products for the EU economies, 18 EU main trading partners, and the rest of the world. Figaro tables are available from 2010 to 2020.

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[32] https://www.exiobase.eu/index.php/about-exiobase

[33] https://worldmrio.com/

Table A.5
Supply chain information

Data source	Key features					Pros and cons
	Confidentiality	**Accessibility**	**Granularity**	**Scope**	**Time coverage**	
OECD - ICIO	Non confidential	Open source	45 industries	66 countries	1995-2018	+ well established in the literature. - low temporal coverage - no environmental extension
FIGARO	Non confidential	Open source	64 sectors/ products	EU + 18 and RoW	2010-2020	+ dataset that builds on the OECD – ICIO - new dataset - no environmental extension
ExioBase	Non confidential	Open source	163 industry and 200 products	44 countries (28 EU plus 16) and five RoW	1995-2022	+ granular environmental extensions available
EORA	Non confidential	Commercial	26 to ~500 industries/ products	190 countries	1990-2021	+ highly granularity and geographic coverage - Commercial license only

4.3.2 Data needs

Although a significant number of data sources are now available, data gaps still persist. For example, measurements and data necessary to conduct a full-fledged financial risk assessment of nature-related physical and transition shocks is missing. This type of data would allow regulators to develop nature stress tests capable of capturing the systemic dimension of nature losses. Furthermore, investments that focus on restoring nature and reversing biodiversity loss are challenged by the lack of sufficient data at business level and lack of standardised biodiversity impact metrics for investors.

It is necessary to create a strong data foundation by compiling biodiversity and other environmental data based on clear and defined standards. A common framework would allow to better determine possible gaps in data and methodologies. At the same time, international standards could help to better assess private and public benefits of different types of biodiversity (e.g. common farmland birds or rare mountain plants) and better define how to preserve them.

More developed tools for spatial integration of environmental and financial data could allow to refine measures of vulnerability of economic activities to ecosystem services. To move from a simple exposure or sensitivity analysis to a risk assessment, finer sectoral and spatial granularity is required. Moreover, interdependencies among different ecosystem services and between nature and climate-change are still missing. These gaps can lead to severe underestimations of nature-related risks. More granular and better integrated data would help to define scenarios that would stipulate how key economic variables are affected by the depletion of one or more ecosystem services.

Table A.6
Key data gaps and identified needs

Data category	Policy relevance	Key missing features			
		Sectoral granularity	**Geographical granularity**	**Scope**	**Methodology**
Common international standards	Better determine gaps and make comparison across policies possible	Standard principles and definitions across different economic activities	Standard principles and definitions across different jurisdiction	The overall coverage should be global	Common standards should not only focus on data but also on the methodologies used
Vulnerability of economic activities to ecosystem services	Risk assessment - granular exposure analysis for financial stability	Finer sectoral granularity (e.g. using the entirety of GICS/NACE)	Completely missing in ENCORE but needed to understand possible concentration risk	Interdependencies between ecosystem services and climate risks missing	Interdependencies between ecosystems missing but needed to identify possible amplification effects
Impact of economic activities on ecosystem services	Test effectiveness of preservation policies - production and consumption-based biodiversity impacts	MSA is relative measure, potential biases in parameter estimates, only global mean temperature increase considered	High-resolution representation, it can aggregate to sub-regional level	Capture the impact of environmental pressure on biodiversity	Quantitative relationships that assess the impacts of anthropogenic pressures on biodiversity
Supply-chain information	Necessary to increase precision of policy analysis (fully map exposure and impact)	Could be refined at NACE 3 level, or even provided at a firm-by-firm level	Could be enlarged to all countries	Finer coverage of inputs (e.g. product wise)	Moving from a country IOT to a firm-specific supply chains.

At the same time, better models and standards that describe the impacts of different types of businesses on biodiversity are necessary. The overall impact that different businesses can have on nature can vary widely, e.g., between mining operations and forestry enterprises. Understanding these interactions is necessary to precisely measure the effectiveness of preservation policies. Data is currently incomplete. Specifically, it is difficult to combine different impact indicators across providers and capture all possible environmental pressures. Existing aggregated measures (see mean species abundancy) do not fully capture all the relevant dimensions of nature.

To produce comprehensive analyses on either the dependency or the impact on nature, more granular supply-chain data is required. Mapping not only direct but also upstream dependencies and impact is of paramount importance in today's globalised world. As an example, a company would need to know the environmental footprint of their suppliers. Only by doing so it would be possible to fully map all the pressures and thus increase the precision of policy analysis.

- **The increased urgency and need to mobilise resources to support nature-based solutions, biodiversity and ecosystem restoration call for bridging the gap between current 'state of nature' assessments and the development of biodiversity finance**. The above mentioned four areas require further development to support public and private investment in nature restoration: compiling more detailed biodiversity data, creating a spatial data infrastructure and impact metrics, developing business-biodiversity impact models and gaining greater insight into the optimal combination of public and private instruments.

- **To successfully tackle biodiversity loss, a combination of biodiversity-linked private investments and public action is needed**. Specifically, there is still the need for comprehensive implementation of biodiversity-related legislation, further changes in national and EU sectoral policies, and better coordination of public and private instruments for landscape-scale restoration. The EEA will explore opportunities to support the development of the required data foundation and impact models and standards, and the testing of new approaches to biodiversity finance. In doing so, it will seek partnerships with financial institutions, data providers and the financial community to enable strong investment in biodiversity and ecosystem restoration as part of the European Green Deal initiative[34].

4.3.3 Available models to assess the relationship between economic activity and ecosystems, needed for moving from exposure to scenario analyses

Capturing the macroeconomic and sectoral consequences of physical or transition shocks would require specific integrated models or modelling frameworks (using a combination of existing models), some of which are starting to emerge. The NGFS categorises existing models in two categories: nature-economy models and biophysical models.

Relying solely on existing nature-economy models[35] will likely lead to undermine the potential risks through which initial nature-related hazards can generate broader sectoral and macroeconomic impacts. Two main factors seem to explain this.

First, the models assessed are currently able to represent the economic impacts of only a small portion of potential physical and transition hazards. Regarding physical risks, provisioning ecosystem services relating to food and timber production tend to be considered by the models assessed (as well as fish stocks and water to a lesser extent), but most models do not capture regulating and maintenance ecosystem services. Regarding transition risks, the focus of existing models is usually on land use change and climate change (but the representation of technical change in agriculture tends to be less developed) while other drivers of biodiversity loss

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[34] See: Financing nature as a solution — European Environment Agency (europa.eu)

[35] The six modelling frameworks reviewed by the NGFS are: GTAP-InVEST, REMIND-MAgPIE, AIM (CGE and PLUM), IMAGE-MAGNET, MESSAGE-GLOBIOM, and GCAM.

such as direct exploitation of resources, pollution and invasive species driver are poorly (if at all) represented by the models reviewed.

Second, the models reviewed tend to underestimate the potential magnitude of the economic consequences of the nature-related hazards considered because of their structure and assumptions. For instance, macro-financial variables such as the impact of a specific trajectory on GDP is usually not captured (the models reviewed are typically calibrated to follow an exogenous path of GDP growth). Moreover, it is usually assumed that nature and the services it provides can (easily) be substituted with others labour or capital, thereby mitigating the economic consequences of potential disruptions in ecosystem services.

Other "biophysical" models (simulations of one or several biological systems, which can be used to predict the influence of biological and physical factors on complex systems) could also be useful to generate nature-related scenarios. For instance, when assessing the ISIMIP models suite36, it appears that biophysical models could help link regulating ecosystem services (e.g. water regulation) to the provisioning services that directly impact the economy (e.g., agricultural yields); this could help better calibrate (for instance) a shock in productivity of the agricultural sector in a macroeconomic model. With regards to transition risks, biophysical models could help design scenario narratives, e.g. by helping design maps of areas that should be protected to achieve a specific land protection target.

Although they can help improve the calibration of nature-economy models, biophysical models cannot solve their inherent limitations. Hence, they cannot provide a solution on their own. Ad hoc solutions may therefore be needed in the short- to medium- term, in parallel to an assessment of the extent to which nature-economy models can be adapted to the nature-related risk assessments. Different options can be envisioned, each carrying different trade-offs.

The first option is to rely on nature-economy models (including those already used for the development of the NGFS climate scenarios) linked to their associated module focusing on land-use and the agriculture sector. Using such models would facilitate the alignment with NGFS climate scenarios, and would also allow investigating the interactions between nature policies (largely restricted to land-use) and climate policies.

However, as discussed above, this will likely largely underestimate the macroeconomic impacts of nature loss and potential policies to revert it, while not covering many nature-related issues.

A second option is to rely on the existing nature-macroeconomic models that have a higher level of sectoral disaggregation and include land in their production function. This sectoral granularity could help capture a broader range of hazards that could directly impact several sectors, while representing the impacts of policies related to land-use on other sectors of the economy.

However, such models are usually tailored to the assessment of marginal shocks and may be less relevant to capture the economic effects of more structural changes. They are also highly sensitivity to parameter values, and in particular to the fact that results can be significantly impacted by even small changes in substitution elasticities in production and utility functions.

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[36] See: **ISIMIP - The Inter-Sectoral Impact Model Intercomparison Project**

Additionally, these rely on a pre-defined GDP growth paths which become important drivers of the very results that are of interest to central banks.

In light of these limitations, input-output tables (such as the ones described in section 1.3.1) could become suitable tools for assessing the indirect impacts of nature-related financial risks in the short- to medium-term (e.g. less than 10 years), i.e. over time horizons in which structural changes are not expected to take place. Indeed, input-output tables can be particularly useful to assess the transmission hazards across sectors and countries when non-substitutable forms of natural capital become stranded. Input-output tables can be used without prior reliance on models, by connecting directly to a specific narrative (see section 1.1.5). They can also be used with other models. For instance, one could plug biophysical models to input-output tables to assess how hazards in one sector/region can propagate towards other sectors/regions. Likewise, it is possible to merge input-output tables with Stock-Flow Consistent models (SFC) models that specifically aim to capture structural change and the nonlinear development of new patterns or technologies, while also accounting for the monetary and financial side of the economy.

Hence, while input-output cannot satisfactorily cover medium- to long-term dynamics (where technical coefficients of sectors will evolve, and where more structural changes could take place), they can provide relatively simple and transparent assessments of the potential impacts of nature-related hazards, and therefore help central banks and supervisors identify potential points of vulnerability within the economic system according to different narratives. They could be used while a more fundamental work on existing models – accounting for the different challenges discussed above – takes place.

4.4 The EU playing field of nature-related policies

When it comes to policy, the EU has long-standing legislations to protect biodiversity. The first legislations were the EU Nature Directives. The EU nature directives — the Habitats (Council Directive 92/43/EEC)37 and Birds Directives (Directive 2009/147/EC) — require conservation efforts for more than 2000 species and habitats of Community interest across the EU. The information about the conservation status of these species and habitats is coming from Member States' reports that are submitted every six years[38]**.**

The Special Protected Areas (SPAs) classified under the Birds Directive, and Special Areas of Conservation (SACs) designated under the Habitats Directive form the Natura 2000 network[39]. The EU's Natura 2000 network of protected areas is at the heart of the European Union's conservation efforts: it currently covers 18.6% of the EU's land area and 9% of its marine territory. Natura 2000 sites are important hotspots for nature conservation. The Natura 2000 network is an overarching measure to be implemented by Member States, and it is a legal framework for applying practical conservation actions. The LIFE programme, and specifically its environment sub-programme is the EU′s major dedicated funding instrument for conservation

[37]

[38] See: https://www.eea.europa.eu/ims/conservation-status-of-habitats-under

[39] https://natura2000.eea.europa.eu/

measures. It provides grants for projects contributing to the implementation of the Nature Directives and the Natura 2000 network.

The new EU Biodiversity Strategy for 2030[40] **is one of the core elements of the European Green Deal (EGD)** [41] **(**Error! Reference source not found.**).** The biodiversity strategy aims to s trengthen and enlarge the network of protected areas, set up a restoration plan and ensure that ecosystems are healthy, resilient to climate change, rich in biodiversity, and deliver the range of services essential for citizens' prosperity and well-being. The EGD recognises the need for a systemic change in response to the coupled climate and biodiversity crises. It is a strategic framework that promotes coordinated policy action. It calls for coherent contributions from diverse policy areas to achieve sustainability transitions in production-consumption systems. It has a specific focus on cross-cutting themes, such as financing, innovation and just transition.

The Farm to Fork Strategy42 is an example of a systemic framework within the EGD with high relevance for climate and biodiversity related risks. It is a policy roadmap that calls for a major transformation of European food systems 'to reduce the environmental and climate footprint of the EU food system and strengthen its resilience, ensure food security in the face of climate change and biodiversity loss and lead a global transition towards competitive sustainability from farm to fork and tapping into new opportunities'.

Table A.7
Key European Union policies for biodiversity

The European Green Deal	**Soil Strategy for 2030**
Biodiversity Strategy for 2030	**Pollinators Initiative**
Birds and Habitats Directives and Natura 2000	**Invasive Alien Species Regulation**
The proposed Nature Restoration Law	**EU Funding instruments**
Forest Strategy	**Adaptation Strategy**
Marine Strategy Framework Directive	**Funding instruments**
Water Framework Directive	

*Sources: **https://biodiversity.europa.eu/policy/biodiversity-policies-at-the-european-level***

The UN General Assembly passed a resolution on 28 July 2022, recognising a clean, healthy and sustainable environment as a human right, which can serve as catalyst for action to streamline the value of nature in broader terms than only economic value in policies. Similarly, in the EU, there is an ongoing debate on corporate liability for environmental damage, the concept of ecocide and its recognition in EU law[43].

[40] See EC (2021)

[41] See EC (XXX)

[42] See EC (2020)

[43] Procedure 2020/2027(INI), EU Parliament resolution **https://oeil.secure.europarl.europa.eu/oeil/popups/summary.do?id=1663548&t=d&l=en**

'Nature-based solutions44 are actions to protect, conserve, restore, sustainably use and manage natural or semi-natural ecosystems. They therefore have the potential to address the sources of physical nature-related financial risks, while also addressing broader social, economic and environmental challenges effectively and adaptively.

4.4.1 Valuing nature

Measuring and monitoring the value of nature informs policies and helps decision-making in response to nature degradation; in general, the value of nature can be determined following various ways including monetary and non-monetary approaches. Integrating values in decisions focusing up-front on avoiding harms to nature and on its contributions to people can help to decrease nature-related risks. People have developed many ways of understanding and connecting with nature. Therefore, diverse approaches exist to conceptualise the values of nature[45].

Economic and political decisions have prioritised certain values of nature, market-based instrumental values in particular.34 However, much broader concepts of nature's contributions to people exist, and used e.g. by IPBES, including diverse ways in which people conceive nature's role in quality of life. The values can be assessed through different world-views, knowledge systems, broad and specific values, and biophysical-, monetary- or socio-cultural value indicators. Over 50 different methods to assess nature's values have been applied in different contexts globally. They include nature-based, behaviour-based, statement-based and integrated methods (**Error! Reference source not found.**). Europe stands out with a high number o f valuation studies among the IPBES subregions. Streamlining the diverse values of nature in decisions is challenging due to the difficulty of comparing or combining them. Making different indicators comparable or compatible is not always possible; in those cases, considering them in parallel requires inclusive discussions with stakeholders. Choosing appropriate valuation methods requires the consideration of their strengths and weaknesses, and their relevance, robustness and resource needs.

[44] https://wedocs.unep.org/bitstream/handle/20.500.11822/39864/NATURE-BASED%20SOLUTIONS%20FOR%20SUPPORTING%20SUSTAINABLE%20DEVELOPMENT.%20English.pdf?sequence=1&isAllowed=y

[45] IPBES, 2022

Table A.8
Valuation methods

	Nature-based valuation	Statement-based valuation	Behaviour-based valuation	Integrated valuation
Definition	It gathers measures or analyses information about the properties of nature and its contributions to people	It directly asks people to express their values	It identifies how people value nature by observing their behaviour and practices	it brings together various types of values assessed with different information sources
Examples of methods and approaches	Biodiversity inventory, ecosystem services mapping, Delphi method, participatory mapping of ecological values	Group discussions, Q-methodology, contingent valuation, choice experiments, deliberative methods	Participant observation, travel cost method, cost-based methods, hedonic pricing, livelihood dependence, photoseries analysis	Ecosystem service valuation, cost-benefit analysis, multi-criteria decision analysis, integrated modelling, scenario building, deliberative decision methods
Use in the report	Section 1.2.1 State of nature in the EU	-	-	Box on Ecosystem accounting, the state of ecosystems in Europe

Sources: IPBES, 2022.34

The EEA biodiversity indicators and the conservation status and trend information for species and habitats are components of nature-based valuation. (Section 4.4.2) They measure mainly intrinsic values that help quantify the inherent value and uniqueness of various species and ecosystems. Intrinsic values are centred on the recognition that nature has intrinsic rights to exist and flourish, irrespective of human utility. The limitation of nature-based valuation is that they do not directly assess the impact on people. However, the information they provide could be possibly used as an input data in a nature-related risk assessment in Europe, in a methodology linking physical or transition risks of certain economic activities with the overall condition of certain habitats or species in a given biogeographic area in a country, as the data is available at that scale. E.g. if an economic activity is dependent on or puts pressure on certain habitats or species, conservation status could possibly indicate the level of physical risk, and/or necessity for required measures to restore habitats or to improve the conservation status of species impacted by the economic activity.

The ecosystem services framework is part of the nature-based valuation and often used also in integrated valuations. It is increasingly used in the science-policy interface, within natural capital accounting. Natural capital accounting is considered one of the key tools to integrate biodiversity considerations into public and business decision making, also by the EU Biodiversity Strategy for 2030. Ecosystem accounts is a system under natural capital accounting, developed specifically to record, explore relationships and track changes in ecosystems, their size and condition (“health”), and to measure the interaction between ecosystems and the economy. It uses the ecosystem services framework to measure. how and how much ecosystems contribute to the economy and the human society. It also aims to measure how human actions affect ecosystems. It uses the principles of economic accounting, centred around the concept that the stock and quality of ecosystems can be seen as an asset to be preserved (Box 2 of the main report). This approach applies monetary accounts based on internationally accepted statistical principles.

4.4.2 Nature-based valuation: Biodiversity data and indicators of the European Environment Agency

Biodiversity and ecosystem indicators focus on a range of topics such as the distribution of selected species, conservation status of habitats and species, ecosystems' coverage in Europe, etc. These data play a crucial role in monitoring ecosystem conditions and capturing the dynamics of ecosystem assets and services. To achieve this, an advanced Ecosystem Accounting framework is utilised (see Box 1 of the main report). This framework enables the systematic tracking of ecosystem health, encompassing the assessment of both ecosystem resource levels and the delivery of essential services to society.

The Biodiversity Information System for Europe (BISE) offers selected data catalogues and infrastructures as reference data related to biodiversity in Europe.

The Water Information System for Europe (WISE) illustrates a wide span of water related information through interactive maps, charts and indicators. Its Freshwater section provides information on the state of Europe's rivers, lakes, groundwaters, on the pressures affecting them, on the measures and actions taken to protect and conserve the aquatic environment which is used as a basis for assessing the status of freshwater resources in Europe. In most of the cases, its data sources are databases reported by EU Member States under legislative reporting obligations, and from EEA member and cooperating countries in a voluntary basis.

The WISE Marine section provides access to information and data on the state of Europe's seas, on the pressures affecting them, and on the actions being taken to protect and conserve the marine environment.

The Forest Information System for Europe (FISE) is the entry point for sharing information with the forest community on Europe's forest environment, its state and development. FISE brings together data, information and knowledge gathered or derived through key forest-related policy drivers.

The EEA datahub enables a further exploration of biodiversity data. Through a network including institutional partners across 38 European countries, EEA collects quality-assured data on a wide set of topics related to the environment, climate and sustainability.

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