Annexes

Report, “The macroprudential challenge of climate change”

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by
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1 Annex - data and measurement

1.1 A framework for monitoring climate-related risks

Climate-related exposures of the non-financial sector are measured by climate-related factors such as greenhouse gas (GHG) emissions in the case of transition risk and by exposures to climate-related hazards such as floods, hurricanes, wildfires and heatwaves in the case of physical risk (see Figure 2 in Section 2 of the report). The impact on the non-financial sector (households and non-financial corporations, NFCs) occurs either through additional costs (e.g. energy costs, carbon tax, risk mitigation and adaptation costs) implying reduced profits or available income, or through damage to physical assets, which leads to a need fors repairs and potentially causes production disruptions. The exposures thus need to be understood in terms of their economic effects. For example, in the case of transition risk, the economic risk to a NFCs may be inversely proportional to their revenues. In this case ”emissions intensity” (emissions over revenue) proxies the risk for a NFC.

The overall impact for an NFC – assuming that marginal risks from exposures remain constant – can be captured by

$$Risk\ to\ nNFC = climate\ exposure \times marginal\ economic\ riskiness(impact)\ of\ climate\ exposure.$$

When this is applied to transition risk for NFCs, such risk would increase with emissions and with marginal impact emissions have on the firm’s activity. The multiplicative representation assumes that the marginal effect is constant, which may not necessarily be the case, but simplifies the development of metrics. The risk metric can also be applied to proxies of marginal climate-related risks.[1]

Exposures of the financial sector to the non-financial sector can be measured on the asset side, based on credit exposures (loans, debt securities, equity), or on the liability side (insurance provisions, derivatives). The resulting risk to the financial sector includes credit risk (probability of counterparty default – PD and associated loss given default - LGD), market risk (asset valuation) and other risk types (operational or reputational risks). For each of the risk dimensions one can compute the marginal riskiness of the exposure from climate-related factors. Assuming that the marginal riskiness of credit exposures is constant, the overall risk to a financial institution from financial exposures is

$$Risk\ to\ financial\ institution = financial\ exposure\ \times marginal\ riskiness\ of\ financial\ exposure.$$

Based on these considerations on exposures and risks, we develop ClimRisk and ClimVul as generalised, institution-specific financial risk and vulnerability metrics.

[1] In the case of the EU- Emissions Trading System scheme, one would further take into account (free) emission allowances which would temporarily reduce the extent of the transition risk.

1.1.1 A generalised climate-related financial risk metric

By combining exposures and risks in the financial and non-financial sector, a generalized climate-related risk of financial institutions – denoted as ClimRisk - can be calculated as

$$\begin{aligned}\boldsymbol{ClimRisk} = {} & climate\ exposure \\ & \times marginal\ economic\ riskiness(impact)\ of\ climate\ exposure \\ & \times financial\ exposure \\ & \times marginal\ financial\ riskiness\ of\ credit\ exposure\end{aligned}$$

This general formulation can be applied to various exposures and risks and serves as a basis for the development of individual risk metrics within a common monitoring framework. Mathematically, it can be formulated as follows:[2]

$$ClimRisk = \sum\nolimits_i \underbrace{\left(Exp_i \times \frac{dEcon_i}{dExp_i}\right)}_{Economic\ risk} \times \underbrace{\left(L_i \times \frac{\partial Risk_i}{\partial Econ_i}\right)}_{Financial\ risk}$$

where

$\boldsymbol{Exp_i}$: exposure to climate-related factors by NFCs (emissions, physical hazards)

$\boldsymbol{Econ_i}$ is economic risk or impact variable (such as costs, profits, assets, etc.)

$\boldsymbol{L_i}$: is exposure of financial to non-financial institutions (such as loans, debt securities, equity, derivatives, insurance liabilities, etc.)

$\boldsymbol{Risk_i}$ is financial riskiness of exposure (losses due to credit defaults or valuation changes).[3]

1.1.2 A generalised climate-related vulnerability metric

Risk metrics require detailed knowledge about the impact of climate-related factors on variables of NFCs (effect on profits or assets) or on financial riskiness (PD, LGD or valuation). Such information is not always available. An alternative class of metrics can consider firms' climate-related exposures and their vulnerability, labelled as climate-related vulnerability metrics ($ClimVul$):

$$ClimVul = \sum\nolimits_i \underbrace{(Exp_i \times EconVul_i)}_{Economic\ vulnerability} \times \underbrace{(L_i \times FinVul_i)}_{Financial\ vulnerability}.$$

The difference between the risk and vulnerability indicators is that the financial vulnerability of the firm is not directly linked to climate-related factors.[4] These types of indicators implicitly

2 The indicator considers the overall effect of exposures on risk: $ClimRisk = \sum_i Exp_i \times L_i \times dRisk_i/dExp_i$, the equation in the main text distinguishes the economic from the financial impact.

3 The individual variables are not fully independent. In general, '$Risk$' is a function of '$Econ$' and climate-related exposures 'Exp': $Risk = Risk(Econ(Exp))$. As a result $dRisk/dExp_i = \partial Risk_i/\partial Econ_i \times dEcon_i/dExp_i$, whereby $\partial Risk_i/\partial Econ_i \leq 0$ and $dEcon_i/dExp_i \leq 0$.

4 It is also possible to combine the vulnerability with the riskiness aspect. For example, if it is possible to assess the impact of climate-related factors on economic variables, such quantification can be combined with a vulnerability metric for the financial dimension.

assume that the existing vulnerability of firms interacts with the risk stemming from climate-related factors, but they do not quantify the transmission of the climate-related factors to the firm itself. Examples of *economic* vulnerabilities can be energy-intense production for transition risk, or, in the case of physical risk, high dependency on water as an input, if the location of the production facility is subject to water stress. In turn, examples of *financial* vulnerabilities are highly indebted firms (debt over revenue), highly leveraged firms (debt over equity) and firms financed by short-term liabilities.

1.2 Applied climate-related exposure, risk and vulnerability metrics

In the following we present applied risk metrics building on the generalized risk and vulnerability metrics, together with their usefulness within a financial stability monitoring framework.

1.2.1 Exposure metrics

Loan-weighted emission intensity

The loan-weighted emission intensity[5] **captures any potential bias in the emission intensity of a financial institution or company's loan exposures.** It is composed of emissions E_i by a NFC i, scaled by its revenue R_i to proxy for its riskiness and multiplies it by the loan exposure L_i of the financial institution to the company, scaled by the overall loan exposures $L = \sum_i L_i$:

$$CFALTL = \sum\nolimits_i E_i \times \frac{1}{R_i} \times L_i \times \frac{1}{L}.$$

This specification indicates that if the marginal impact of emissions on profitability $(dEcon_i/dExp_i)$ is $-1/R_i$ and the marginal riskiness of the exposures for the lender $\partial Risk_i/\partial Econ_i$ is $-1/L$, the loan-weighted emission intensity could be interpreted as a risk metric. However, since this may stretch the logic of the framework, we consider the loan-weighted emission intensity rather as an exposure metric of financial institutions.

[5] The International Monetary Fund (IMF) has labelled this inidicator "Carbon Footprint-Adjusted Loans to Total Loans" (CFALTL), see Climate Change Indicators Dashboard (**https://climatedata.imf.org/**).

1.2.2 Risk metrics

A PD-based transition risk metric

The PD-based transition-risk metric accounts for the riskiness of firms as captured by PD (PD_i), LGD (LGD_i) or market risk (M_i) as potential risk dimensions, i.e. dPD_i/dE_i, $dLGD_i/dE_i$, and dM_i/dE_i. A PD-based transition risk metric is calculated as

$$ClimRisk_{Tran\_PD} = \sum_i E_i \times \frac{1}{R_i} \times L_i \times \left|\frac{\partial PD_i}{\partial \pi_i}\right|.$$ [6]

The metric implies that there is a marginal impact of emissions on profitability of $-1/R_i$ and the effect on PD transmits exclusively via the profitability channel: $dPD(\pi_i)/dE_i = \partial PD_i/\partial \pi_i \times d\pi_i/dE_i = -\partial PD_i/\partial \pi_i \times 1/R_i$.

An LGD-based physical-risk metric

The framework can equally be used for physical risk exposures. For example, assuming that the risk from a physical hazard H on a firm's LGD (LGD_i) is transmitted via the assets used as collateral, the climate risk metric becomes:

$$ClimRisk_{Phys\_LGD} = \sum_i H_i \times L_i \times \frac{dLGD_i}{dH_i} = \sum_i H_i \times \underbrace{\frac{dA_i}{dH_i}}_{Damage\ fct.} \times L_i \times \frac{\partial LGD_i}{\partial A_i}.$$

In this case, H_i reflects the exposure to the physical hazard – potentially measured through scores - and A_i the assets of the firm. The impact of the hazard on LGD_i can be decomposed into its effect on assets (asset destruction) and a separate effect of asset deterioration on LGD: $dLGD(A_i)/dH_i = \partial LGD_i/\partial \times dA_i/dH_i$.[7]

A valuation-based market risk metric

The valuation of a company depends on multiple factors. It combines the current conditions of the firm as well as forward-looking information on the transition and the firm's own adjustments to the transition. In addition, market risk (risk to valuation of assets) depends on the financial instruments and differs between equity and debt security exposures, for example. In the following we consider emission and physical risk exposures jointly but as independent risks, i.e. not correlated (for the sake of simplicity).

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[6] We opted to write the expression with the absolute value of marginal riskiness to simplify notation, as the $d\pi_i/dE_i = -1/R_i$.

[7] The marginal impact of hazards on assets is expected to be positive ($dLGD_i/dH_i \geq 0$), but the individual components are negative ($\partial LGD_i/\partial A_i \leq 0, dA_i/dH_i \leq 0$), ensuring an overall positive value for the ClimRisk metric. For the special case that A_i are firms' tangible assets pledged as collateral $\partial LGD_i/\partial A_i = -1$ and that a materialization of physical risks implies full destruction of the assets $H_i \times dA_i/dH_i = -1$ (100% destruction), the climate risk metric would take the value L_i of the financial exposures.

$$ClimRisk_{market} = \sum_i \left(E_i \times \frac{d\pi_i}{dE_i} + H_i \times \frac{dA_i}{dH_i}\right) \times \left(L_i \times \left(\frac{\partial valuation_i}{\partial \pi_i} + \frac{\partial valuation_i}{\partial H_i} + \frac{\partial valuation_i}{\partial H_i \partial \pi_i}\right)\right)$$

The market climate risk indicator captures the risk of emissions and damages from physical hazards affecting the valuation of a company via its profits and assets. The overall risk for such a portfolio can be calculated by using damage functions to assess the physical destruction of assets and can capture forward-looking aspects through profit-valuation relationships such as those implied by the Merton model for valuations. In the forward-looking case, the progression from climate-related factors to valuation requires expectations for future profits and future assets, combined with appropriate discount factors that also reflect risk preferences.

1.2.3 Vulnerability metrics

Vulnerability metrics are relevant because the effect of climate-related factors on economic and risk metrics of NFCs is not always quantifiable. In the following we present four metrics that directly integrate firm-level and bank-level information.

The Transition to Credit Intensity (TCI) by Emambakhsh (2021)

This indicator focuses on firms' PD (PD_i) and emission intensity (E_i/R_i) as vulnerability metrics, capturing the overall riskiness of these firms from a lenders' perspective. The vulnerability of an individual firm is $E_i/R_i \times PD_i/L_i$ and can be aggregated to a loan-weighted metric for a financial firm:

$$TCI = \frac{1}{L}\sum_i \underbrace{\left(E_i \times \frac{1}{R_i}\right)}_{Economic\ Risk} \times \underbrace{\left(L_i \times \frac{PD_i}{L_i}\right)}_{Financial\ Vulnerability}$$

The term 1/L normalises the indicator by the total financial exposures of a financial firm for comparability.

Climate risk sensitivity (CRS) by Emambakhsh and Kouratzoglou (2021)

The CRS metric measures the sensitivity of bank portfolios to the rising financial risk of borrowers stemming from climate risk in terms of the increase in expected losses (EL_i) relative to loan exposures (L_i). It is calculated for each bank's credit exposure as

$$CRS = \frac{1}{L}\sum_i \underbrace{(\beta_{ROA}\,\Delta(profitability)_t + \beta_{lev}\Delta(leverage)_t)}_{Economic\ Risk} \times \underbrace{\left(\frac{EL_i}{L_i}\right)}_{Financial\ Vulnerability}$$

where β_{ROA} and β_{lev} are sensitivity coefficients that determine to what extent borrower PD reacts to changes in profitability (return on assets, ROA) and leverage, estimated from the economy-wide climate stress test.[8] The term 1/L normalises the indicator by the total financial exposures of a financial firm for comparability.

Indebtedness vulnerability indicator

The indebtedness vulnerability indicator considers "loans over revenue" as a metric for firm indebtedness and a firm's vulnerability

$$ClimVul_{indebt} = \frac{1}{L}\sum_i \underbrace{\left(E_i \times \frac{1}{R_i}\right)}_{Economic\ Risk} \times \underbrace{\left(L_i \times \frac{L_i}{R_i}\right)}_{Financial\ Vulnerability}$$

Here $ClimVul_{ind}$ resembles the decomposition of the loan carbon (emission) intensity LCI, but with an inverted ratio for indebtedness:

$$LCI = \sum_i \frac{E_i}{L} = \frac{1}{L}\sum_i \underbrace{\left(E_i \times \frac{1}{R_i}\right)}_{Economic\ Risk} \times \underbrace{\left(L_i \times \frac{R_i}{L_i}\right)}_{?}$$

The LCI captures the emissions per unit of a credit (loan) exposure. The decomposition into emission intensity (E_i/R_i), loan share (L_i/L) and inverted indebtedness (R_i/L_i) reveals that the LCI does not represent a suitable headline vulnerability metric for firms as it uses the inverse of firm indebtedness (instead of the indebtedness ratio itself).

Nevertheless, the components of the indicator may be useful for separate analysis (emission intensity, share of loans and indebtedness). In addition, the LCI - as a unit of emission intensity in exposure portfolios - can be used to track the adjustment of financial exposures and as a potential metric for the efficiency of transition financing, for example new generation financing.

Leverage vulnerability indicator

The leverage vulnerability indicator combines ROA and emission intensity:

$$ClimVul_{lev} = \sum_i E_i \times \frac{1}{A_i} \times L_i \times \frac{1}{L} = \sum_i \frac{E_i}{R_i} \times \frac{R_i}{A_i} \times \frac{L_i}{L} = \frac{1}{L}\sum_i E_i \times \frac{L_i}{A_i}.$$

This indicator captures the degree to which financial firms are exposed to high emitters relative to their (tangible) assets instead of revenue (see $CFALTL$ in Section 2.1).[9] The metric can be rewritten as emission intensity multiplied by ROA or, alternatively as emissions multiplied by the firms' accounting leverage (L_i/A_i). The focus on (tangible) assets in E_i/A_i provides an indication of the firms' reliance on a polluting capital structure. A high value of the indicator would suggest that the bank is exposed to companies with high dependency on emitting capital structures

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8 See Alogoskoufis, S., Dunz, N., Emambakhsh, T., Hennig, T., Kaijser, M., Kouratzoglou, C., Muñoz, M.A., Parisi, L. and Salleo, C., "**ECB economy-wide climate stress test – Methodology and results**", Occasional Paper Series, No 281, ECB, September.

9 Adjustments of the indicator via exposures L_i has a more muted effect due to the scaling factor $L = \sum_i L_i$. An adjustment via assets A_i and may thus affect the interpretation and comparison of the indicator across institutions.

and subsequently large investment needs for the transition. For capital-intensive firms in particular, this poses a risk of becoming stranded.

1.2.4 Household transition risk

The following presents a technique for estimating a household's energy and emissions within a national credit register (CR), see Box 2 in the main report. This methodology is built upon the assumption that many CR variables are correlated with energy consumption. The method first explores the relationship between these variables and household energy consumption by estimating energy consumption using national Household Budget Survey (HBS) data. Household energy expenditure and emission variables are then estimated by combining model results based on the HBS with borrower characteristics.

Two core datasets are employed (additional auxiliary data sources are listed in the method below):

- The HBS is a representative survey for most European countries carried out every five years, primarily in order to capture changes in household expenditure patterns and calculate weightings for the consumer price index. The most recent survey was conducted in 2015 (the 2020 survey was delayed due to the coronavirus (Covid-19)), and the results are available for all euro area Member States. The survey collects data on all household expenditure items, including how much households spend on energy. For most expenditure items, households maintains a detailed expenditure diary over a two-week period.[10] For irregular items, such as electricity bills, households provide their most recent bill amount, which is converted into indicative weekly figures for consistency. The HBS also contains extensive data on occupants, employment and income.
- Mortgage loan-level data (LLD) are acquired from the Central Bank of Ireland Monitoring Templates, which were introduced in 2016 to monitor bank compliance with mortgage measures under macroprudential regulations. In the current exercise, a random sample of new mortgages (n = 10,000) from 2018 to present (March 2022) is employed. Lending for this period represents approximately 30% of total outstanding mortgage balances.

The method involves five steps:

1. Identify variables which are correlated with household energy/efficiency and are available in both datasets (LLD and HBS). In the current setting, the Irish mortgage LLD and HBS each contain data on employment, age, income, property size, property type and province
2. Create a total annual energy consumption variable (within the HBS): convert mean weekly expenditure data (electricity, gas, petrol, diesel and solid fuels) into an annual total energy expenditure estimate for each household

[10] HBS data entries are weekly figures – the final figures used here represent the average of the two weeks.

3. Convert energy expenditure into CO2 emissions (within the HBS): divide each fuel expenditure by common fuel prices (converts expenditures to quantities) and then apply emissions conversion factors for each fuel (converts quantities into emissions)

4. Estimate household energy consumption and emissions (ordinary least squares regression) – which include the common variables identified in Step 1 (within the HBS) plus month dummy variables (month of household survey) to control for seasonal variation: in the Irish models, all variables were statistically significant and of the expected sign

5. Using coefficient values from Step 4, populate LLD loans with estimates of energy and emissions (estimate based on each loan's borrower and property characteristics)

Energy price sources (used in Step 3)

Fuel	Unit	Source	Notes
Electricity	kWh	**Eurostat**	Band DC employed
Gas	kWh	**Eurostat**	Band D2 employed
Petrol	Litre	**Worldbank**	
Diesel	Litre	**Worldbank**	
Kerosene (Oil)	kWh	Use national source	If applicable
Solid Fuels (Coal)	kWh	Use national source	If applicable

CO2 intensity sources (used in Step 3)

Fuel	Unit	g CO2 per Unit	Source
Electricity	kWh	Country dependent	**EEA – European Environment Agency**
Gas	kWh	204.7	**SEAI – Sustainable Energy Agency of Ireland**
Petrol	Litre	2,392	**Ecoscore (Belgium)**
Diesel	Litre	2,640	**Ecoscore (Belgium)**
Kerosene (Oil)	kWh	257.0	**SEAI - Sustainable Energy Agency of Ireland**
Solid Fuels (Coal)	kWh	340.6	**SEAI - Sustainable Energy Agency of Ireland**

1.2.5 Damages from flood risk exposures and expected credit loss

Exposure to flood risk for banks in Italy in Box 1 of the report is quantified in terms of the share of the stock of banks' loans to firms located in areas at (flood) risk with respect to total credit to firms. Credit data are derived from the AnaCredit register; raw data on flood risk include information per the Register of Institutions and Affiliations Data (RIAD) on the simulated water raise due to a river/costal flood with return periods of 10, 50, 100, 200 and 500 years in the reference period1990-2013 (JRC Risk Data Hub).[11]

For each return period under consideration the exposed credit is computed as the total outstanding credit to RIAD entities if water rise due to a river/coastal flood is non-zero. The exposure of credit at risk is measured as the share of exposed credit for each return period over total outstanding credit.

The exposure can be used to compute the expected credit at risk should the catastrophic event (i.e. a flood) materialize. In the exercise we assume that for each counterpart the credit losses correspond to the share of the damaged building. This percentage is measured according to the depth-damage curves developed in Huizinga et. al. (2017). These damage curves represent the share of assets that is damaged at a given flood depth for a variety of asset classes and building types (industrial, commercial or mixed).

Table A.1
Damage function for flood risk across countries.

Damage class	Flood depth (m)	Damage function						
		Europe	North America	Central and South America	Asia	Africa	Oceania	Global
Commercial buildings	0	0	0.02	0	0	-	0	0
	0.5	0.15	0.24	0.61	0.38	-	0.24	0.32
	1	0.3	0.37	0.84	0.54	-	0.48	0.51
	1.5	0.45	0.47	0.92	0.66	-	0.67	0.63
	2	0.55	0.55	0.99	0.76	-	0.86	0.74
	3	0.75	0.69	1	0.88	-	1	0.86
	4	0.9	0.82	1	0.94	-	1	0.93
	5	1	0.91	1	0.98	-	1	0.98
	6	1	1	1	1	-	1	1
Industrial buildings	0	0	0.03	0	0	0	-	0
	0.5	0.15	0.32	0.67	0.28	0.06	-	0.3
	1	0.27	0.51	0.89	0.48	0.25	-	0.48
	1.5	0.4	0.64	0.95	0.63	0.4	-	0.6
	2	0.52	0.74	1	0.72	0.49	-	0.69
	3	0.7	0.86	1	0.86	0.68	-	0.82
	4	0.85	0.94	1	0.91	0.92	-	0.92
	5	1	0.98	1	0.96	1	-	0.99
	6	1	1	1	1	1	-	1

Source: JRC Risk Data Hub.

JRC damage functions are used to calculate the share of the losses on the outstanding exposed credit to the intermediary in case of flood for each return period. By aggregating the data over the different entities, it is possible to derive the expected credit loss due to flood risk using the methodologies described in Antofie et al. (2020) and applied in the Data supplement to ECB/ESRB (2021). Finally, we define five percentage buckets of credit at risk, ranging from less

[11] The individual events are assumed to be independent as information on the correlations between single events is not available.

than 1%, to above more than 20%. For each return period, we present, for both coastal and river floods, the share of banks in each bucket.

1.3 Financial market-based and system-wide metrics

1.3.1 Climate risk from real economy and financial interlinkages

Systemic approaches provide a suitable analytical framework to account for the indirect effects associated with the transition to a low-carbon economy to provide estimations of the system-wide exposure to transition risks (Section 2.3.2 of the report). Using input-output data, Cahen-Fourot et al. (2021) measure the sectoral physical capital at risk of stranding due to a reduction in fossil fuel extraction, considering both direct and indirect channels stemming from a reduction in fossil fuel extraction. Their results indicate that some sectors, such as the chemical industry, are more exposed when including indirect effects from interdependent sectors, considering both input and output dependencies.[12]

The methodology proposed for this metric builds on input-output data to provide a snapshot of the intersectoral real economy interdependencies for demand and supply shocks. The exercise assumes two stylised transition shocks to cover for both demand- and supply-side disruptions that are transmitted through the value chains and create second-round effects. The first shock is a negative supply shock to reduce fossil fuels in line with the Paris Agreement climate targets.[13] The shock represents a loss in the factor of production (labour or capital) in the fossil fuel sectors, which then reduces the production and spreads through the supply chain based on a Ghosh (1958) model. Specifically, the implementation considers that fossil fuel's factor of production reduces by a range of 10-30% over five years. The second shock considered is a drastic policy measures to reduce global demand of fossil fuels by 10-30% over five years. Demand in each sector is affected depending on their sector's direct CO_2 emissions, with impacts trickling down the production system following a Leontief (1919) model.

To estimate the impact of a supply or demand disruption on bank asset quality we develop a proportionality factor related to output losses and applied to the PD of loans. The proportionality factor relates the estimated country-sector-specific losses in gross value added (GVA) from the input-output analysis to firm-level PD. In this way firms in country/sectors with higher output losses receive a higher than average PD increase, proportional to the larger output loss in the sector and country in which they operate. For example, a firm in a sector with an expected GVA loss of 1% would see a doubling of its firm-level PD.[14] In this way the analysis

[12] Similarly, Godin and Hadji-Lazaro (2022) show how the loss of coal exports can have significant indirect effects on the South African economy.

[13] The numerical implementation is more stringent to account for delays in implementing the necessary regulations to reduce fossil fuel consumption.

[14] The baseline calibration of the model combines individual firm-level PDs for non-financial and financial companies, derived from the Expected Default Frequency (EDF) measure developed by Moody's (2021). Values in the upper tail of the firm-level PD distribution are capped with the values at the 95th percentile to avoid skewing results when proportionally scaling PDs. The remaining banking exposures are captured by sector aggregates net of the exposures captured by granular data. In addition to financial and non-financial corporations, the sectors also include households and sovereigns.

integrates the firm-level PD reflecting firm-specific risk profiles with sector-level risks from the demand/supply disruptions.[15]

PD increases are applied proportionally to the country-sector effects resulting from the I/O analysis. For the supply reduction, the most affected sectors at NACE 2 level are the manufacture of petroleum products, the extraction of coal, the extraction of petroleum and gas, the manufacture of wood products, and electricity and gas; when considering the implementation through the demand reduction, the most vulnerable sectors are air transport, the extraction of coal, the extraction of petroleum and gas, land transport, and electricity and gas. In turn, bank credit exposures towards vulnerable sectors are concentrated in electricity and gas, land transport, and the manufacture of wood products (see Chart A.1). Furthermore, Eastern European countries as well as Greece are relatively more exposed with exposures to sectors vulnerable to both demand and supply shocks exceeding 2% of total assets for Latvia, Slovakia and Greece. However, exposures to vulnerable sectors are low overall, with the euro area average not exceeding 1% of total assets.

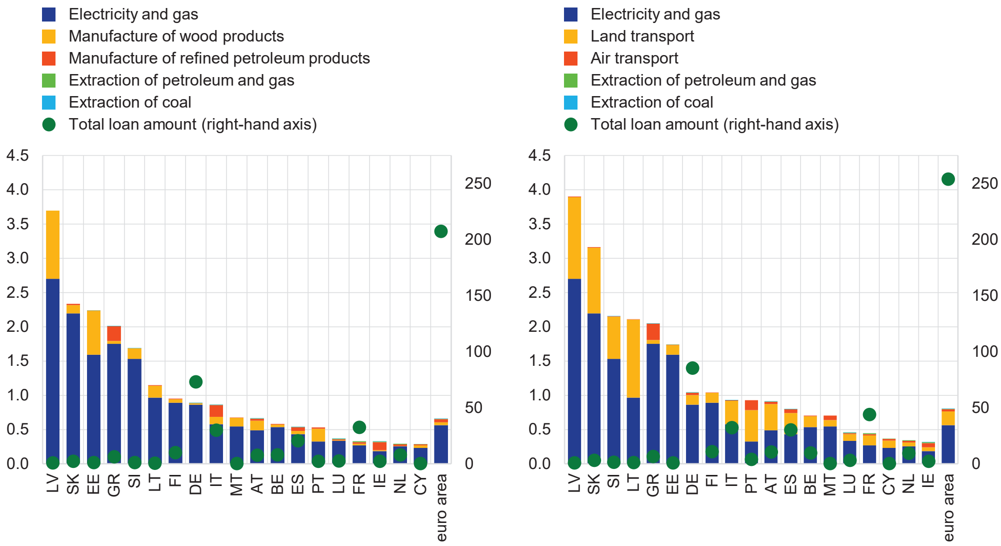
Chart A.1.

Exposures to most vulnerable sectors

(percentages)

a) Supply shock *b) Demand shock*

(y-axis left-hand side: percentages of total assets, y-axis right-hand side: € billions) *(y-axis left-hand side: percentages of total assets, y-axis right-hand side: € billions)*



Sources: AnaCredit, Supervisory data and ECB calculations

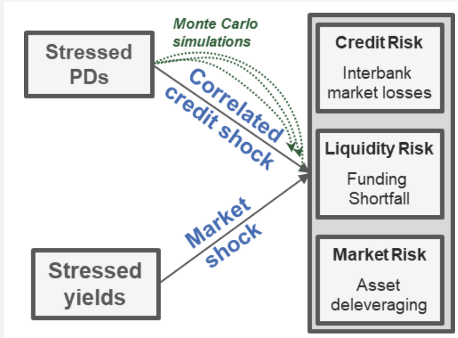
15 The modelling implies that initial vulnerabilities are exacerbated by the relative impact of supply/demand disruptions, an assumption which may not hold for all individual firms.

Box A1
Interbank contagion model

The changes in the proportionality factor across sectors can be used to explore the impact of the disruption on euro area banks for a range of output-PD multipliers. The PD increase generates additional credit losses for banks, which are calculated by simulating individual defaults of firms. Should banks breach solvency requirements (MDA threshold or minimum requirements) they intend to restore their balance sheets through asset sales, potentially triggering spillovers to the banking system via fire sales from common securities holdings or defaults on interbank exposures. Such adjustments would potentially place pressures on asset valuations and generate contagion within the banking system through common exposures.[16]

The ECBs interbank contagion model is a micro-structural model using highly granular data and considers banking system losses and distress in response to shocks. The model generates estimates of bank-level and banking system losses as a result of risk propagation through one of three (interacting) contagion channels: (i) credit risk from vulnerable real economy exposures; (ii) liquidity risk spreading via short-term interbank exposures; and (iii) fire sale risk from common securities holdings (Covi et al., 2019).

Credit risk originates, depending on the scenario's impact on default frequencies, from individual firm defaults, including cross-firm correlations. The losses resulting from defaults interact with each bank's liquidity and solvency conditions whereby a breach of regulatory requirements puts banks into distress.



As a bank's capital position deteriorates, it faces increasing liquidity risk. Distressed banks are assumed to face stigma in inter-bank funding markets and hoard liquidity because other credit institutions no longer roll over short-term instruments to them. These two elements lead to shortages in market liquidity within the banking network, thereby amplifying contagion through the system. In turn, a breach of minimum capital requirements (currently defined to include P1 & P2R) or the inability to pay back creditors due to liquidity shortages, triggers a bank's default which generates interbank credit losses as the bank defaults on the exposures to other counterparties (a 40% loss rate is applied to account for recovery).

Illiquid banks can raise liquidity and strengthen solvency by selling securities from their portfolios. But such fire sales will affect security prices through a stressed pricing function for individual securities (valuation channel). This indirect contagion leads to losses for other institutions

[16] The model generates estimates of bank level and banking system losses as a result of risk propagation through (i) credit risk from vulnerable real economy exposures; (ii) liquidity risk spreading via short-term interbank exposures; and (iii) fire sale risk from common securities holdings. The losses from corporate defaults interact with each bank's liquidity and solvency conditions whereby a breach of regulatory requirements puts banks into distress. Distressed and illiquid banks can raise liquidity and strengthen solvency by selling securities from their portfolios. Such fire sales will affect security prices through a stressed pricing function for individual securities (valuation channel) and implies losses for other institutions with overlapping marked-to-market portfolios (contagion).

with overlapping marked-to-market portfolios. Moreover, insolvent institutions sell all their remaining assets, further depressing prices. After the first round of contagion, additional banks may fall fallen into distress or default, giving rise to iterative losses. The contagion process is repeated until no additional defaults or distress arise.

The differences in the sectoral impact of transitional demand and supply shocks implies that aggregate balance sheets are more sensitive to policy measures affecting demand. The broader range of sectors affected by a demand shock increases the PD more markedly across sectors. Chart A.2 shows the results of the sensitivity when looking at an expected (mean) outcome. In the case of a 30% reduction in fossil fuels via supply shocks and a 300% PD increase, up to 4.5% of euro area banks' risk-weighted assets (RWAs) are estimated to fall below the MDA threshold (Chart A.2, panel a, blue dot). In the case of a demand shock, the banking system results are more vulnerable, with an increase of sectoral PD by 200% resulting in 4% of banks' RWAs falling below the MDA threshold (Chart A.2, panel b, blue line). In both cases banks' RWAs are estimated not to exceed 5% under a simultaneous 30% supply and demand reductions and a 300% PD increase applied to sectors with GVA reduction of 0.5 percentage points.

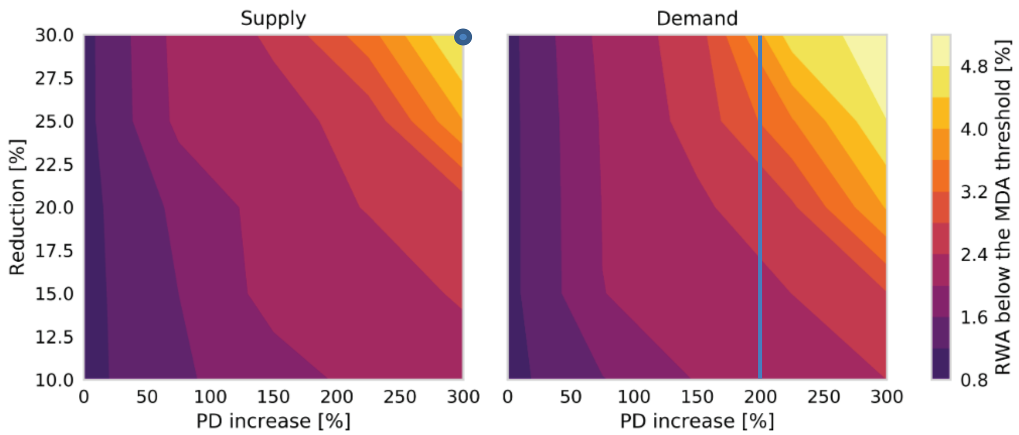
Chart A.2

Banks' risk-weighted assets below the MDA threshold under the baseline scenario

(percentage of total euro area risk-weighted assets)

a) Supply shock – banking system effects following a 10-30% reduction in fossil fuel production factors

b) Demand shock – banking system effects following a 10-30% reduction in global demand



Sources: Supervisory data, Securities Holding Statistics, Exiobase, and ECB calculations.
Notes: Increases in PD refer to increases for firms affected by an average euro area output loss, with the credit quality associated with higher (lower) output loss deteriorating proportionally more (less). The sample includes 2,130 banks between SIs and LSIs.

When looking at a tail outcome, the estimated impact on banks is more significant. Up to 20% of banks' RWAs are estimated to fall below the MDA when considering a 30% reduction in global demand for fossil fuels combined with a PD increase of 300%, applied to sectors with a GVA loss of 0.5 percentage points (Chart A.3). In the case of a 30% reduction in fossil fuel production factors, up to 12.5% of banks' RWAs are estimated to fall below the MDA with a 300% PD increase.

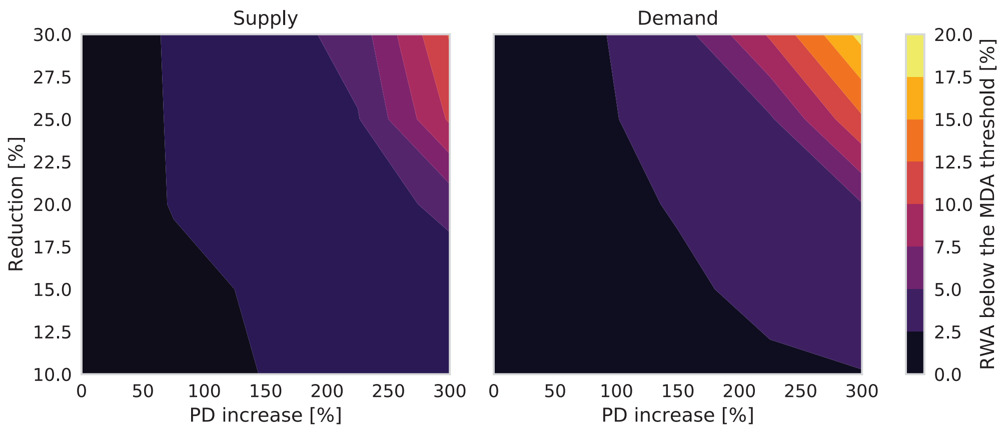
Chart A.3

Banks' risk-weighted assets below the MDA threshold under a tail outcome

(percentage of total euro area risk-weighted assets)

a) Supply shock – banking system effects following a 10-30% reduction in fossil fuel production factors

b) Demand shock – banking system effects following a 10-30% reduction in global demand



Sources: Supervisory data, Securities Holding Statistics, Exiobase, and ECB calculations.
Note: The adverse scenario corresponds to the mean of the simulations where system-wide losses are between the 93rd and 97th percentile.

1.3.2 Banking system losses due to appreciation of transition risk

The methodology proposed in Section 2.3.3 of the report to quantify bank losses due to transition risk from risk appreciation involves two steps (Alessi et al, 2022). First, the proportion of high-carbon and fossil-fuel-related assets in bank's balance sheet is used to adjust the RWAs of banks, thus reflecting the increased riskiness of financing harmful activities. Second, using a model based on individual bank balance sheet data to simulate crisis scenarios allows to investigate how the aggregate loss distribution for the banking sector changes when transition risk through higher risk weights is taken into account.

Step 1: Recalibration of RWAs

The calculation of RWAs assumes that high-carbon and fossil-fuel-related assets between 15% and 25% are more risky than other assets. Notably, the model assumes an increased riskiness by 25% (β_1) for securities and corporate loans financing high-carbon and fossil fuel-related activities, and an increased riskiness of 15% (β_2) for mortgages financing particularly energy-inefficient buildings. The augmented RWAs accounting for transition risks (RWA_{tr}) are derived for each bank as follows:

$$RWA_{tr} = (\beta_1\varphi_{2,c} + \beta_2\varphi_{2,c})RWA + (1 - \varphi_{1,c} - \varphi_{2,c})RWA,$$

where $\varphi_{1,c}$ represents the country-specific share of fossil fuel related activities in banks' balance sheets and $\varphi_{2,c}$ represents the share of mortgages financing highly inefficient properties. Estimates of the $\varphi_{i,c}$ shares are based on Alessi and Battiston (2021).[17]

Step 2: Simulation model

The modelling strategy is based on the Systemic Model of Banking Originated Losses (SYMBOL, De Lisa et al., 2011). The model uses bank-level data to simulate banking crisis scenarios in which individual banks may default based on their actual capital and on PD attached to their portfolio.[18] In a Monte Carlo simulation, the model generates shocks that hit banks and cause unexpected losses (UL):

$$UL_{i,j} = LGD \cdot N\left[\sqrt{\frac{1}{1-R_i}}N^{-1}(PD_i) + \sqrt{\frac{R_i}{1-R_i}}N^{-1}(\alpha_{i,j})\right],$$

where i refers to the individual banks in the sample and $j$denotes the Monte Carlo iteration, R_i is the correlation among the exposures in the portfolio, LGD is the loss given default equal to 0.45 as per Basel regulation, and $N^{-1}(\alpha_{i,j})$ are correlated normal random schoks. Each random shock is defined as the sum of a common shock Z_i and a bank specific shock W_i.

In each iteration, the following two components are summed for each bank: (i) losses that cannot be absorbed by capital, and (ii) recapitalizations needed to bring the bank back to a viability status, i.e. a regulatory capital ratio at 8% of RWAs. The aggregated loss distribution (at the country or EU level) is computed as follows:

$$L_j = \sum_{i=1}^{I} \max(UL_{i,j} - K_i + 8\%RWA_i, 0).$$

A crisis situation corresponds to the very right tail of the aggregate loss distribution, i.e. iterations where the size of the underlying shock is particularly large (more than 3 standard deviations from the mean).

[17] The shares of equity, bonds, mortgages and corporate loans in banks' balance sheets at the country level are based on domestic and cross-border intra-euro area positions provided by the ECB. The coefficients above are applied to each of these asset categories.

[18] The bank's portfolio is derived by numerical inversion of the Basel Fundamental Internal Risk Based formula for credit risks, based on total minimum capital requirements declared in the balance sheet.

Results: transition risk as a trigger of a crisis

The focus of the analysis on conditions in which no banks fail in the absence of transition risk, but some do fail when transition risk materializes. Corresponding aggregate losses are obtained as follows:

$$L_{tr} = \mathbb{E}_j\left[L_j \ j \ in \ \tilde{j}\right], \text{ where } \tilde{j} := \begin{cases} j \text{ such that } L_i > 0 \text{ with transition risk} \\ j \text{ such that } L_i = 0 \text{ without transition risk} \end{cases}$$

The additional losses and bank defaults can trigger an amplification mechanism in the following way: First, banks reallocate their portfolio by selling a share (θ) of their FFAs. Second, this initial sell-off leads to a devaluation (δ) of such assets (fire sales). As a result, additional losses are incurred by the banking system and if additional banks fail, a further devaluation of FFAs follows. Formally, the share of FFAs changes at each round (r) of the fire sale is as follows:

$$FFA_r = \begin{cases} FFA_r \cdot (1-\theta) \ if \ r = 1 \\ FFA_{r-1} \cdot (1-\delta_{tr}) \ if \ r > 1 \end{cases}$$

while the size of the devaluation of FFAs at each round is linked to the number of failing banks in the system (D):

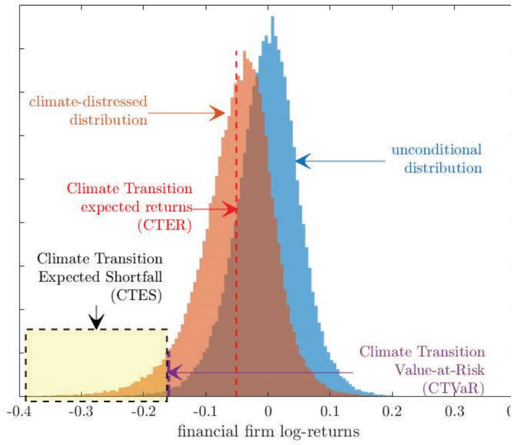
$$\delta_r = \begin{cases} 0.003 \ if \ r = 2 \\ \max\left(\frac{D_{r-1} - D_{r-2}}{D_{r-2}}, 0.003\right) \ if \ r > 2 \ and \ D_{r-1} > 0 \end{cases}$$

1.3.3 Climate transition risk measure for financial firms

In this annex to the climate transition risk measures (Section 2.3.4), scenarios are defined in terms of the expected asset price adjustment following Ojea-Ferreiro, Reboredo and Ugolini (2022). Given a specific scenario, the statistical formulas for the different risk measures (Chart A.4) are presented, i.e. climate transition expected return (CTER), climate transition value-at-risk (CTVaR) and climate transition expected shortfall (CTES). r_g, r_n, and r_b denote the market returns of green, neutral, and non-green emission intensive firms, respectively, with a joint distribution $F(r_g, r_n, r_b)$.

Chart A.4

Climate transition risk measures



Source: JRC calculations.

Note: The blue distribution of stock returns is unconditional, while the orange one is conditional on a consistent stock market scenario with the Network for Greening the Financial System narrative.

Thus, in a disorderly transition scenario, abrupt policy constraints on the use of non-green carbon-intensive energy may cause operational difficulties for firms that are more exposed to risk, ultimately affecting the value of their assets (e.g., assets may become stranded). By contrast, firms with lower exposure to transition risk face a privileged position in the market (unless highly exposed firms in the meantime adapt their production processes to the new circumstance). As a result, market expectations regarding green asset prices curve upwards, with the opposite happening for non-green asset prices. This impact can be described in terms of upward and downward movements of green and non-green asset market returns, as described by their quantiles as: $r_g \geq q_g^\beta$ and $r_b \leq q_b^\alpha$, where the α- and β-quantiles of green and non-green carbon-intensive asset returns are given by $P(r_b \leq q_b^\alpha) = \alpha$ and $P\left(r_g \leq q_g^\beta\right) = 1 - \beta$.

In a hot house world scenario, policy actions to favour transition are implemented slowly and tardily, and investors adjust their expectations accordingly. As non-green firms have more time to offload stranded assets without suffering a large price impact, non-green asset prices increase, while green asset prices decline as green firms lose the opportunity to boost their business. Thus, the relative price impact of a hot house world scenario can be described in terms of upward and downward movements of non-green and green asset market returns, characterized by their quantiles as: $r_g \leq q_g^\alpha$ and $r_b \geq q_b^\beta$, where the α- and β-quantiles of green and non-green asset returns are given by $P(r_g \leq q_g^\alpha) = \alpha$ and $P\left(r_b \leq q_b^\beta\right) = 1 - \beta$. Arguably, the returns of neutral assets in both extreme scenarios experience no particular impact as they are barely affected by the transition to a low-carbon economy.

Finally, in the orderly transition scenario, policy constraints to meet climate transition goals are implemented smoothly, allowing firms to progressively adapt to the new business framework. Investors would therefore expect asset returns to move around their median values (i.e., with no abrupt price changes), described as: $q_b^L \leq r_b \leq q_b^U$, $q_n^L \leq r_n \leq q_n^U$ and $q_g^L \leq r_g \leq q_g^U$, where q_j^L and q_j^U are the lower and upper quantiles around the median for the asset $j = g, n, b$. r_i represents the market returns of financial firm i.

The CTER is the expected return of financial firm i in the event of a climate transition stress scenario. For a disorderly transition scenario, this return is defined as:

$$\boldsymbol{CTER_i = E\left(r_i \,\middle|\, r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}\right)}$$

$$= \int_{-\infty}^{\infty} \boldsymbol{r_i \frac{f\left(r_i,\, r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}\right)}{P\left(\, r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}\right)}\, dr_i}, \quad \text{(1)}$$

where the second equality follows from the definition of conditional expected value, and where $f(\cdot)$ denotes the joint density of financial institution i and the disorderly transition scenario, $P(\cdot)$ is the probability of the disorderly transition scenario determined by $F(r_g, r_n, r_b)$ and, finally, $f(\cdot)/P(\cdot)$ is the density of the financial institution i conditional on a disorderly transition scenario. Changing the values of the conditional variables in equation (1), we easily obtain the value of CTER for a hot house world scenario as $E\left(r_i \,\middle|\, r_b \geq q_b^{\beta}, r_g \leq q_g^{\alpha}\right)$, whereas for an orderly transition scenario the value of CTER is given by: $E\left(r_i \,\middle|\, q_b^L \leq r_b \leq q_b^U, q_g^L \leq r_g \leq q_g^U, q_n^L \leq r_n \leq q_n^U\right)$.

In addition, the systemic impact of a climate transition scenario can also be assessed using CTVaR, defined as the minimum possible return of a financial institution in a climate transition scenario over a given time horizon for a confidence level of $1-\gamma$. For a disorderly transition scenario, this quantity is given by:

$$CTVaR_i^{\gamma} = F^{-1}_{i|r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}}(\gamma), \qquad \text{(2)}$$

where $F_{i|r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}}(\cdot)$ is the probability distribution of r_i conditional on a disorderly transition scenario, with $CTVaR_i^{\gamma}$ as the quantile verifying that $P\left(r_i \leq CTVaR_i^{\gamma} | r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}\right) = \gamma$. Changing the conditional distribution in equation (2) by $F_{i|r_g \leq q_g^{\alpha}, r_b \geq q_b^{\beta}}(\cdot)$ or by

$F_{i|q_b^L \leq r_b \leq q_b^U, q_g^L \leq r_g \leq q_g^U, q_n^L \leq r_n \leq q_n^U}(\cdot)$, we obtain the CTVaR for a hot house world scenario and an orderly transition scenario, respectively.

Finally, the tail effects from a climate transition scenario can be assessed using the CTES, defined as the average value of the financial institution returns falling below its CTVaR value. For a disorderly transition scenario, this is defined as:

$$\boldsymbol{CTES_i^{\gamma} = E(r_i | r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}, r_i \leq CTVaR_i^{\gamma})}$$

$$= \int_{-\infty}^{CTVaR_i^{\gamma}} r_i \frac{f\left(r_i, r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}\right)}{P\left(r_g \geq q_g^{\beta}, r_b \leq q_b^{\alpha}, r_i \leq CTVaR_i^{\gamma}\right)} dr_i. \tag{3}$$

As above, changing the values of the conditional variables in equation (3) produces the CTES for the alternative hot house world and orderly scenarios. Ojea-Ferreiro et al. (2022) employ a vine copula framework to translate the joint density functions into a combination of marginal density functions and a set of dependence functions (copulas) that, combined in a hierachical way, reflect the interrelationships between the different assets in the joint density.

2 Annex - main policy initiatives by institutions

Stocktaking of the ongoing discussion on policy options at international and European level

Many initiatives are underway to assess the extent to which climate-related financial risks (CRFRs) need to be considered in banking supervision and regulation – and the role for macroprudential policy. At the global level, the Basel Committee on Banking Supervision (BCBS) and the European Banking Authority (EBA) have launched initiatives to explore whether the current banking regulatory framework can sufficiently capture the unique features of CRFRs. With regard to supervision, the BCBS launched a public consultation on a set of principles for the effective management and supervision of CRFRs[19] ending in February 2022. The EBA has published its report on environmental, social and governance (ESG) risk management and supervision[20], which outlines how banks and supervisors should integrate ESG factors into their risk management and supervision. Recently, it also published a discussion paper (EBA, 2022) on the role of environmental risk in the prudential framework.[21] The European Commission's draft for amendments of the EU Capital Requirements Directive explicitly clarifies that the existing systemic risk buffer framework can be used to address climate risks. In parallel, the Commission will further consider the suitability of the macroprudential framework for addressing climate risks in the context of its review of the European macroprudential framework.

Similarly, work has been launched on how to deal with CRFRs in the non-bank financial sector and from a cross-sectoral perspective. Regarding the insurance sector, the EU Commission has already started new initiatives in the context of its work on integrating sustainability risks in the prudential framework for insurers[22] and the European Insurance and Occupational Pensions Authority (EIOPA) has already published several deliverables.[23] At the international level, the International Association of Insurance Supervisors (IAIS) has also launched several work streams. Multiple initiatives on new rules for green bonds and investment funds are well under way. In July 2021 the Commission published a proposal for a European green bond standard while rules aimed at fostering transparency and a better integration of sustainability risks

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[19] See See BCBS (2021), "**Principles for the effective management and supervision of climate-related financial risks**", Consultative Document, November.

[20] See EBA (2021), "**EBA report on management and supervision of ESG risks for credit institutions and investment firms**", June.

[21] ECB Banking Supervision has already published its **guide on climate-related and environmental risks**.

[22] See European Commission Delegated Regulation (EU) 2021/1256 and COM(2021)581, and the European Commission's 2020 Solvency II review proposal suggesting an assessment of the dedicated prudential treatment of exposures related to assets or activities associated substantially with environmental or social objectives (Art. 304 "Reviews as regards sustainability risks")

[23] See EIOPA (2021), "**EIOPA further contributes to sustainable finance**", press release, 8 July.

in the investment fund sector are progressively entering into force.[24]. Work by the Financial Stability Board (FSB) on climate risks will support cross-sectoral consistency and a macroprudential perspective in the review of regulatory and supervisory practices and tools that allow authorities to effectively address climate-related risks to financial stability.

International bodies have made significant progress in identifying and quantifying environmental and CRFRs and in raising financial institutions' awareness of climate change and its implications for their business. Policy initiatives concerning disclosures, taxonomies, development of analytical frameworks and indicators and the closing of data gaps can be considered crucial steps in identifying and measuring such risks and the impact they may have on the solvency of financial institutions. According to the Network for Greening the Financial System (NGFS)[25], significant progress has been made by supervisors and regulators in terms of setting supervisory expectations for climate-related and environmental risk management since 2019. Nevertheless, supervisors have made less headway in effectively integrating these risks into their set of formal and binding supervisory tools, although most of them report ongoing actions or plans to do so. At the same time, the banking sector, including banks directly supervised by the ECB, have been slow in implementing such supervisory expectations.[26]

At the current stage, international discussions are still focusing on the potential use of microprudential requirements. International and European discussions are ongoing on the potential amendments to the banking regulatory framework across the three pillars. Work on the justification of a dedicated Pillar 1 treatment for assets associated with climate-related and environmental risks in the prudential framework is currently ongoing at the EBA and BCBS level. So far supervisory efforts have mostly focused on enhancing Pillar 2 and Pillar 3 tools. The fact that they allow for institution-specificities to be taken into account, their key role in incorporating risks not fully captured by Pillar 1[27], and their flexibility make them the natural point through which climate-related and environmental risks can be included in the supervisory process. Scenario analysis and stress testing may be used to assess the need of additional loss-absorbing capacity to cater for the presence of those risks. Institutions' exposure to climate-related and environmental risks may prompt supervisory action on the way institutions identify, monitor, measure and control such risks. Some supervisors expect that, in the near future and once the relevant supervisory review framework is updated, the review and evaluation process could substantiate decisions about capital add-ons covering climate-related and environmental risks.

The discussion on whether macroprudential tools could be appropriate to address environment and climate-related risks has recently gained momentum at the European and international level. The FSB has launched work that aims to provide a system-wide perspective on climate risks and will assess the need for additional macroprudential tools. Furthermore, the EBA and the ESRB have started to explore whether current macroprudential tools are appropriate

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[24] In particular, Regulation (EU) 2019/2088 on sustainability-related disclosures in the financial services sector (SFDR applies from March 2021, with UCITS, AIFMD, insurance based investment products, portfolio management, financial and insurance advice in scope.

[25] See Network for Greening the Financial System (2021), "Progress report on the Guide for Supervisors", October.

[26] See Elderson, F. (2021), "**How well are European banks managing their climate-related and environmental risks?**", The Supervision Blog, ECB, 22 November.

[27] Climate-related and environmental risks drivers may already be taken into account to some extent by P1 requirements, either in the context of operational risks or credit risk - once reflected in PD or LGD estimates or in the due diligence process on credit ratings and internal models.

and sufficient to prevent and mitigate financial stability risks arising from the changing nature of systemic risks due to climate change, as part of the Commission call for advice on the macroprudential review. Close cooperation with these fora will help to advance the discussion. A significant contribution comes from academia, which, although still being scant, already offer an overview of possible tools – existing and new – that can be explored to address CRFRs, both from a microprudential and macroprudential perspective. Nevertheless, to the best our knowledge, the academic literature is mainly focused on the banking sector.

Ongoing activities by national authorities are mostly related to defining climate-related and environmental disclosures. The NGFS (2021) progress report provides a summary of the feedback received from respondents to the NGFS stock-take survey on disclosures[28]. The results highlighted a growing effort to provide public disclosures on climate-related risk. Of 38 respondents, 34% reported the implementation of mandatory climate-related or environmental disclosures within their jurisdictions, and 40% are considering introducing or strengthening existing disclosure requirements. Another policy initiative introduced is the new capital requirements to address climate-related risks (by the Prudential Regulation Authority in the United Kingdom and the Office of the Superintendent of Financial Institutions in Canada). Further to the supervisory initiatives mentioned above, other policy initiatives by national authorities include the introduction of lending facilities to fund green projects (Bank of Japan), mandatory environmental compliance for accessing credit (Banco Central do Brasil) and the integration of sustainability factors into the asset and reserve management framework (Sveriges Riksbank, De Nederlandsche Bank). Several countries have also published their strategy on integrating sustainability into their mission and policy work (Banco de Portugal, Sveriges Riksbank, Federal Reserve of New Zealand, among others) and their commitment to help implement the Paris Agreement (for example, De Nederlandsche Bank).

[28] See Box 1 of **NGFS progress report** for a description of the methodology of NGFS surveys.

• In 2019 The European Commission (EC) has launched the European Green Deal , an initiative with the aim of making the European Union a resource-efficient and competitive economy, ensuring no net emissions of GHGs by 2050 and economic growth decoupled from resource use. To this end, the Commission has since 2018 been developing a comprehensive policy agenda on sustainable finance, comprising an action plan on financing sustainable growth and, more recently, the development of a new strategy for financing the transition to a sustainable economy. This strategy places emphasis on a coherent and effective implementation of the foundations of the sustainable finance framework and identifies four policy areas where further steps are needed:

1. Financing the transition to sustainability, beyond investments and activities that are already sustainable, whatever companies' starting points.

2. Ensuring an inclusive sustainable finance framework, in particular for individuals and SMEs.

3. Increasing the financial sector's resilience to risks and its contribution to sustainability (double materiality perspective). Stress testing - at entity level, supervisory level, and macro-financial stability level – is an important feature of this work.

4. Promoting an international consensus for an ambitious global sustainable finance agenda.

• The Commission is also coordinating international efforts on the mobilisation of capital flows and the integration of sustainable markets through its international platform on sustainable finance. Through its own advisory platform composed of experts from the private and public sector, the Commission has made a number of proposals, including a standard for European green bonds, and published a delegated act on Taxonomy disclosures under Article 8 of the Taxonomy Regulation. In terms of some of its planned initiatives, the Commission intends to launch a public consultation on ESG ratings and credit ratings.

• In October 2021 the Commission also published a proposal to amend the Capital Requirements Regulation and Capital Requirements Directive. Among other things, the proposed amendments introduce binding requirements and mandates for the EBA on the integration of ESG risks in banks' risk management and internal stress testing. Banks will also have to develop specific plans for transition risk management with clear targets to address identified risks from misalignment with EU sustainability policies. Supervisory powers are also given to ensure that banks manage ESG risks adequately, including by tackling ESG risks in the Supervisory Review and Evaluation Process (SREP) (Pillar 2) and by identifying them through supervisory stress-testing. Additionally, the proposal integrates information on banks' exposure to ESG risks into supervisory reporting. Moreover, it brings forward to 2023 the EBA's mandate to assess whether a dedicated prudential treatment of exposures related to assets and activities subject to environmental and/or social effects would be justified.

• In August 2021, delegated acts were published to amend the undertaking for collective investment in transferable securities (UCITS) and Alternative Investment Fund Managers Directive (AIFMD) regimes to integrate sustainability risks and factors. UCITS management companies and alternative investment fund managers will have to consider sustainability features for their decision-making processes, identification of conflicts of interest, assessment of necessary resources, due diligence processes and risk management procedures. With the integration of sustainability risks and factors, investment funds will be individually more resilient against climate-related risks.

• Rules on the integration of sustainability risks into operational and organisational obligations imposed on investment firms were published in August 2021, via amendments to the Markets in Financial Instruments Directive (**MiFID) delegated acts.** Sustainability has been introduced until the last link of the investment chains through amendments to the MiFID and Insurance Distribution Directive (IDD) frameworks to create and integrate clients' "sustainability preferences" of clients into the advisory process and product governance. As of 2 August 2022, financial advisers will be required to enquire about their clients' sustainability preferences, and offer products that match such preferences. This will strengthen the consideration of sustainability preferences, address the risks of greenwashing and further contribute to the financial system's transition. Therefore, the amendments to the MiFID and IDD frameworks further address greenwashing and avoid the resulting mis-selling.

• In April 2021 the Commission adopted changes to the technical rules of Solvency II (Delegated Regulation (EU) 2021/1256). Insurers need to ensure that sustainability risks relating to their investment portfolio are properly identified, assessed and managed. Furthermore, insurers must take into account the potential long-term impact of their investment strategy and decisions on sustainability factors. In risk management, insurers are mandated to assess and manage the risk of loss or of an adverse change in the values of liabilities resulting from inadequate pricing and provisioning assumptions due to sustainability risks. In September 2021, the Commission published a proposal to amend the Solvency II directive. The proposal suggests an assessment of a specific prudential treatment of investments related to ESG risks and a regular review of the capital requirements for underwriting natural catastrophe risks. The treatment of climate-related risks is one of the central points proposed in the review of Solvency II, in particular through enhancing the own risk and solvency assessment (ORSA) with climate change scenario analysis. The solvency capital requirement is calibrated with a one-year horizon, while climate risks may materialise or affect insurers' vulnerability over a longer-term. The impact of climate change is already evident today, but might further raise underwriting risk, impact asset values and pose a challenge to the current business models of many (re)insurers. The amended regulation proposes and specifies a framework for climate change scenario analyses to be carried out by undertakings in their ORSA. Insurers should first assess whether there are material exposures to climate change risks and then carry out at least two long-term scenarios (global increase in temperature (1) below 2°C and (2) equal to or higher than 2°C). The approach should constantly be reviewed and adapted as new methodologies become available and as undertakings gain experience. Proposed amendments to the ORSA, as well as to the prudent person principle would require insurers and supervisors to take a systemic view and account for systemic risks in risk management and investment activities. Insurers should take into account the impact of macroeconomic and financial market developments, including climate change, on their risk profile, business decisions and solvency needs, and reciprocally assess how their activities may affect macro-economic developments and turn into sources of systemic risk (i.e. the double materiality assessment). As climate change is expected to affect the entire (re)insurance sector, supervisors would also be able to provide input to specific undertakings, particularly as regards systemic risks and concerns, taking into account the dimension of interconnectedness.

• The regulatory framework for pension funds already has provisions aimed at addressing CRFRs. The second Directive on Institutions for Occupational Retirement Provision (IORP II) adopted in December 2016 introduced requirements for IORPs' to conduct an own risk assessment, new rules to improve governance and transparency and enhanced powers for supervisors. The directive also introduced requirements in relation to ESG risks, emphasising the need to improve risk management and include risks associated with climate change and stranded assets in the scope. The directive describes ESG factors, as referred to in the principles for responsible investment, being important for the investment policy; within the prudent person rule Member States should allow IORPs to take into account the potential long-term impact of investment decisions on ESG factors. Member States are also required by the directive to ensure that IORPs disclose the relevance and materiality of ESG factors, and how they are considered in their risk management system. Nonetheless, it is sufficient for IORPs to state that ESG factors are not considered in their investment policy or that the costs to monitor the relevance and materiality of these factors are disproportionate in relation to their activities to fulfil the directive's requirement.

• The Sustainable Finance Disclosure Regulation (SFDR) makes mandatory for UCITS and alternative investment fund **managers, most life insurance companies, pension funds, investment firms and credit institutions performing portfolio management, and financial advisers to disclose a set of sustainability-related information.** The SFDR requires these entities to inform end-investors about sustainability risks, including physical and transition risks, that may affect the value of their investments, how they manage these and what is the impact on the financial value of the investments. With the potential to indirectly affect their management of CRFRs, the SFDR foresees that they have to disclose information on the negative externalities (or adverse impact) of their investment decisions on the environment (i.e. the double materiality concept). The SFDR also requires disclosure on how offered financial products promoting environmental or social characteristics or having sustainable investment objectives meet such characteristics or objectives through product disclosures. In February 2021, the joint European Supervisory Authorities delivered to the Commission draft Regulatory Technical Standards (RTS) on the content methodologies and presentation of disclosures under the SFDR. The proposed RTS aim to strengthen protection for end-investors by improving ESG disclosures on the principal adverse effects of investment decisions and on the sustainability features of a wide range of financial products, thus reducing the risk of greenwashing. A second set of RTS were published under the SFDR in October 2021 that amend the draft published in February 2021 and their accompanying templates in order to minimise duplication and complexity.

• As part of the 2018 Action Plan, the EU adopted amendments to the Benchmark Regulation (Regulation (EU) 2019/2089 amending Regulation (EU) 2016/1011), that introduced mandatory sustainability-related transparency requirements for all benchmarks, including specific key performance indicators for benchmarks embedding ESG in their methodology. The amendments also created two new climate-related benchmarks labels, namely EU Paris-aligned benchmarks and EU climate transition benchmarks, to clarify the market offering of benchmarks pursuing climate-related objectives and to cater for the needs of investors seeking to align their portfolio with the objectives of the Paris Agreement. While primarily useful for directing capital towards sustainable investments, the EU Climate Benchmark Regulation and the introduction of the two types of labelled benchmarks and ESG disclosure requirements for all benchmarks will enhance transparency and help to prevent greenwashing.

• **The EU taxonomy, by providing a homogeneous classification and definitions of environmentally sustainable activities, will to some extent help financial market participants to manage CRFRs.**

• **The ECB/European banking supervision is working with the members of the European System of Central Banks and the ESRB to contribute to the analysis and management of climate-related risks at the global and European levels.** Specifically, the ECB is contributing to the development of an analytical framework for climate risk assessment; the development of indicators for a climate risk monitoring framework for the European financial sector and of methodologies for climate stress tests or sensitivity analyses, and will explore possibilities to fill identified data gaps; and to the development of the EU green taxonomy through its membership of the European Commission's Technical Expert Group on Sustainable Finance. The ECB also considers the use of macroprudential policies for any material systemic risks, including climate-related ones. On the supervisory side, the ECB/SSM will conduct a full supervisory review of banks' practices for incorporating climate risks into their risk frameworks, based on a dedicated Supervisory Review and Evaluation Process methodology that will eventually influence banks' Pillar 2 capital requirements. Moreover, in this effort to understand the impact of the climate crisis from a financial risk perspective, the ECB/ European banking supervision considers that banks need to develop transition plans compatible with EU policies implementing the Paris Agreement, with concrete intermediate milestones. In its Macroprudential Bulletin of October 2021, the ECB also proposes the creation of a green capital markets union as a means to developing sustainable, integrated and resilient European capital markets. The development of sizeable, mature and integrated green EU capital markets also requires decisive action to strengthen capital markets beyond the sustainable finance segment, notably by advancing on the EU capital markets union.

• **The EBA has also taken several initiatives, based on various legal mandates received from the Commission.** In 2020 the EBA began to integrate ESG factors and risks into the banking regulatory framework. First, the EBA introduced sustainability considerations into the guidelines on loan origination and monitoring published in May 2020. The EBA published in June 2021 a final report on the management and supervision of ESG risks for credit institutions and investment firms, which served as the basis for the future development of guidelines on banks' identification, measurement, management and monitoring of ESG risks and for the incorporation of ESG risks into the SREP guidelines. In March 2021, a comprehensive EBA report was also published, complementing the EBA opinion of February on the disclosure requirement for environmentally sustainable activities in accordance with Article 8 of the Taxonomy Regulation. In January 2022 the EBA published technical standards on Pillar 3 disclosures of ESG risks for large listed banks and class 2 investment firms, which includes the definition of the green asset ratio. These technical standards will allow stakeholders to assess bank's ESG-related risks and sustainability strategy and will promote market discipline. In May 2021 the results of an EU-wide pilot exercise on climate risk were published in which the EU corporate exposures of a sample of volunteering banks underwent a mapping and sensitivity analysis in relation to climate risk. Related to Pillar 1, a discussion paper will be published for consultation in the second quarter of 2022, which will assess the justification of a dedicated prudential treatment for assets associated with environmental objectives and/or subject to environmental effects and ask for stakeholders' input before publishing a final report on the topic by June 2023. Finally, the EBA published in March 2022 a report to develop a specific framework for sustainable securitisation as mandated by the Securitisation

Regulation following the amendments introduced by the European Commission's COVID-19 recovery package. The report assesses the implementation of the EU taxonomy and of sustainability-related disclosures in the area of securitisation. It also investigates the possible effects of a sustainable securitisation framework on financial stability, the scaling-up of the EU securitisation market and bank lending capacity.

• The Sustainable Finance Roadmap 2022 - 2024 proposed by the European Securities and Markets Authority identifies three priorities for ESMA's sustainable finance activities over the three coming years: (i) tackling greenwashing and promoting transparency; (ii) building national competent authorities' and ESMA's capacities in the sustainable finance field; and; (iii) monitoring, assessing and analysing ESG markets and risks. Furthermore, based on ESMA's advice on the integration of sustainability risks and factors in UCITS, AIFMD and MiFID II, the European Commission adopted delegated acts to amend these regimes. ESMA has also published recommendations on how to define key performance indicators to qualify the activities of businesses as environmentally sustainable under the EU taxonomy framework. In January 2022, ESMA published a consultation on guidelines for certain aspects of the MiFID II suitability requirements. In February 2022 ESMA also published a call for evidence on the market characteristics of ESG rating providers in the European Union.

• EIOPA has pursued a number of initiatives that support the insurance and occupational sectors' adaptation and mitigation of climate-related risks. EIOPA is developing a dashboard on insurance protection gaps for natural catastrophes, which aims to represent the drivers of climate-related insurance protection gaps and identify measures that will help in decreasing society's losses in the event of natural catastrophes.[29] The potential role of (re)insurers in contributing to climate adaptation and mitigation, while supporting the insurability of climate change-related risks was explored in a report on non-life underwriting and pricing in the light of climate change, referred to as impact underwriting.[30] EIOPA has further set out expectations on the integration of climate change risk scenarios into insurers' ORSAs[31]. Moreover, EIOPA has published a methodological paper on the potential inclusion of climate change in the Nat Cat standard formula[32] and will be mandated to regularly review the scope and the calibration of parameters of the standard formula pertaining to natural catastrophe risk.[33] EIOPA has further published a proposal to require prudential reporting on climate risks to investments[34]. As part of its sustainable finance activities from 2022 to2024, EIOPA will continue to work on the integration of ESG risks into the prudential framework of insurers and pension funds, including deepening the analysis on prudential ”Pillar 1” capital treatment for both assets and liabilities.[35]

• The BCBS has set up a Task Force on Climate-related Financial Risks (TFCR), which is charged with contributing to the Committee's mandate of strengthening the regulation and

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29 For more information, see EIOPA's initial work on the dashboard **here**.

30 EIOPA (2021), "**Report on non-life underwriting and pricing in light of climate change**", 8 July.

31 EIOPA (2021), "**Opinion on the supervision of the use of climate change risk scenarios in ORSA**", 19 April.

32 EIOPA (2021), "**Methodological paper on potential inclusion of climate change in the Nat Cat standard formula**", 8 July.

33 For more information, see the European Commission's proposal on the Solvency II review, 22 September 2021 (**here**).

34 EIOPA (2022), "**Draft Amended Implementing Technical Standards (ITS) on supervisory reporting and disclosure**", 31 March.

35 EIOPA (2021), "**Sustainable finance activities 2022-2024**", 7 December.

supervision of banks worldwide and ensuring that banks are better prepared to address risks related to climate change. The TFCR workplan includes three workstreams to assess each pillar of the Basel Framework: the regulatory framework; supervisory review process and practices; and disclosure requirements. The work is being undertaken through the following lead-off initiatives: a set of analytical reports on CRFRs, including reports on the transmission channels of such risks to the banking system as well as on measurement methodologies; the development of effective supervisory practices in order to mitigate CRFRs; and a comprehensive analysis to identify any potential gaps in the Basel Framework and develop appropriate measures to address them. The Basel Committee has also published analytical reports on CRFRs. Its report on "climate-related risk drivers and their transmission channels", published in April 2021 concludes that "traditional risk categories used by financial institutions and reflected in the Basel Framework (e.g. credit risk, market risk, liquidity risk, operational risk) can be used to capture climate-related financial risks". In terms of supervision work, the TFCR reviewed the Basel Core Principles and Pillar 2 supervisory review process and developed high-level principles for the effective supervision of CRFRs and banks' risk management practices in the form of BCBS Guidelines. In November 2021 the Basel Committee has published on the consultative paper on the "principles for the effective management and supervision of CRFRs". The Committee is coordinating its work with similar initiatives underway in other international fora and standard-setting bodies.

• The International Organization of Securities Commissions (IOSCO) has provided guidance to member jurisdictions on the issuance of new regulations and disclosure requirements related to environmental risks. IOSCO has also set forth a number of recommendations to securities regulators and policy makers on how to improve sustainability-related policies and disclosures in the asset management industry

• The FSB promotes globally consistent and comparable disclosures by firms of their CRFRs. The FSB roadmap focuses among other areas on regulatory and supervisory practices and tools both within individual sectors and at the system-wide level. Furthermore, it suggests that supervisory and regulatory approaches to climate-related risks should be fully integrated within the overall supervisory and regulatory approaches to address financial risks. In some jurisdictions, climate-related risks are being integrated into the microprudential supervision of banks and insurance firms (including via requirements for firms' stress testing and disclosure). However, such work is generally at an early stage.

• The NGFS has published a guide for supervisors that puts forth a set of recommendations on how to integrate climate-related and environmental risks into supervision frameworks. Recognising the importance of scenario analysis and stress testing for managing climate-related risks, the NGFS has also published a Guide for Climate scenario analysis that details how supervisors can carry out their scenario analysis or stress tests. In particular, NGFS scenarios provide a framework for supervisors and financial institutions to engage in forward-looking climate-related risk analysis.

• The G20 has established the G20 Sustainable Finance Working Group (SFWG) with the objective of scaling up sustainable finance that contributes to the achievement of the 2030 Agenda and the Paris agreement. The SFWG has also developed the G20 Sustainable Finance Roadmap: a multi-year document that defines the broad G20 agenda on climate and sustainability. The roadmap is structured in two parts. In the first part, key priorities for scaling up sustainable finance are outlined. In the second part, a list of actions and indicative timelines are proposed in order to meet the defined priorities.

• Contributions from think tanks support the development of green macroprudential tools to tame financial risks related to climate change, although the academic literature on this topic is recent and scarce (see Chapter 4.4 of the report). Some think tanks such as the Institute for Climate Economics (I4CE), the Macroeconomic Policy Institute (IMK) and the 2° Investing Initiative (2DII) have published reflections on green differentiated capital requirements. For instance, M. Berenguer et al. (2020) analyse how capital requirements can be used to address climate-related risks, making a clear distinction between the development of green macroprudential tools to tame financial risks related to physical, transition, and liability risks (risk approach), and the increase of financial resources devoted to green investments (policy approach). Chamberlin and Evain (2021) find that, from an empirical approach based on French banks, the effects of a green supporting factor (even high) are too limited to stimulate new projects across all transition sectors, while a dirty penalising factor would need to be both high and applied to a limited scope in order to accelerate the planned withdrawal from certain fossil fuel-based activities. Dafermos and Nikolaidi (2021) argue that the combination of green fiscal policy and a dirty penalizing factor is a potentially effective climate policy mix from a financial stability point of view. The 2° Investing Initiative, in a 2021 paper on financial supervision beyond the business cycle, broadens the debate on differentiated capital requirements by considering “long-term risks (LTRs)”, including climate change but also pandemics, and social resilience. Beyond capital requirements, P. D'Orazio and L. Popoyan (2019) propose a comprehensive analysis of the pros and cons of various existing macroprudential instruments, including for instance the countercyclical capital buffer, the sectoral systemic risk buffer, credit floors or ceilings, or large exposures limits.

• The Bank of England published its supervisory expectations for enhancing banks’ and insurers’ approaches to managing the financial risks from climate change with a deadline for firms to have embedded them as far as possible by the end of 2021. The Prudential Regulation Authority has also defined its expectations in regard to the banks’ and insurers’ disclosures of financial risks generated by climate change. Supervised institutions are already required to hold capital for exposures significantly exposed to climate-related risks. A UK joint government and financial regulator taskforce is defining the required steps in order to achieve mandatory disclosure rules aligned with the Task Force on Climate-related Financial Disclosures (TCFD) across all UK’s non-financial corporations, which is required for the financial sector to provide a full disclosure of its exposure to climate-related risks.

• In March 2021, De Nederlandsche Bank (DNB) published its first progress report on the steps to identify and mitigate climate-related risks in the areas of asset and liability management, supervision of the financial sector, economic advice and statistics. In an update of its supervision priorities in November 2020, DNB highlighted the importance of adequate identification and control of sustainability risks in the supervision of banks, insurers and pension funds. It also published its bank-wide sustainable finance strategy in July 2021, outlining the sustainability-related targets for its core activities.

• The Banque de France and the Autorité de contrôle prudentiel et de resolution (ACPR) have taken a number of initiatives to address climate issues. In 2020 the ACPR notably launched a climate pilot exercise, i.e. a stress test on financial risks linked to climate change by

2050, the results of which were published in May 2021. In March 2021, the Banque de France announced the creation of a Climate Change Centre responsible for coordinating the Banque de France and the ACPR in terms of taking climate issues into account, analysinge the risks associated with climate change for the financial sector and coordinating with the NGFS. The Banque de France has also implemented a responsible investment approach for its portfolios. The responsible investment report describes the institution's efforts to incorporate climate issues into the management of its own funds and pension liability investment portfolios. The report defines the objective of aligning its portfolios with a sub-2°C global warming trajectory while promoting the funding of the economy's transition to a decarbonised society.

• **As part its strategy to integrate sustainability into its policy work, Sveriges Riksbank has outlined that it will only purchase bonds issued by a companies compliant with international standards of sustainability.** The central bank will also report the carbon footprint of its corporate bond portfolio. In addition, Riksbank has integrated sustainability factors into the management of its foreign exchange reserves, and the composition of its reserves will now consider the impact of its assets on GHGs.

• **In regard to sustainability and sustainable finance, one of the priorities of the Banco de Portugal is to monitor the implications of climate change and energy transition for monetary policy and financial stability, two core missions of the central bank.** In the financial stability field, it continuously assesses Portuguese banks' exposures to NFCs belonging to economic sectors more vulnerable to transition risks. In the supervisory area, it has extended to less significant institutions the ECB's guide for climate-related and environmental risks, which sets out the expectations for European banks to prudently manage and transparently disclose such risks under current prudential rules.

• **In 2018 Banco Central do Brasil (BCB) published new rules for social, environmental, and climate-related risk disclosures by financial institutions.** This new set of rules for disclosure was inspired by, but not limited to the recommendations of the TCFD. The scope was enlarged to include social and environmental issues considered relevant for Brazil. In 2017 the BCB implemented its policy for socio-environmental responsibility within the financial system. Brazil has a rich background on sustainability-related measures, including for instance the definition of mandatory environmental compliance for accessing rural credit in the rainforest area and the monitoring of drought effects and their impact on the national financial system.

• **The Financial Services Agency in Japan (JFSA) requires financial and non-financial companies to disclose material information on climate-related risk.** The JFSA established its disclosure recommendation in accordance with CFD recommendations. Additionally, the JFSA has established an export panel to explore ways to mobilise capital for a smooth transition towards a decarbonised society. In June 2021, the Bank of Japan (BoJ) announced that it would support the transition to a carbon-neutral economy by using targeted refinancing operations to fund to investments or loans that address climate change issues. The lending facility provides funds at a preferential rate for projects in growth areas identified by the BoJ in conjunction with banks and other economic partners.

• **The Monetary Authority of Singapore has published its guidelines on environmental risk management that set out supervisory expectations on the disclosure of environmental risks**

by financial institutions, directly referring to TCFD recommendations. Financial institutions are expected to disclose both their approach to managing environmental risk and the potential impact of such risk on their operations. In its sustainability report, the central bank describes its effort to create a green finance hub as part of Singapore's strategic approach to the transition to a green society.

• **The Council of Financial Regulators, which is the coordinating body for Australia's main financial regulatory agencies, has taken important steps to improve the ability of corporations and financial institutions to manage the financial risks associated with climate change.** According to financial regulators climate change activity stocktake in 2021, the ongoing work can be grouped under four broad themes: (i) using scenario analysis to measure the exposures of financial institutions and the financial system to climate-related risks. A cornerstone of which is the climate vulnerability assessment focusing on the climate risk of the five largest Australian banks; (ii) setting supervisory expectations for financial institutions regarding climate change; (iii) improving the quality and consistency of corporate climate risk disclosures; and (iv) monitoring the development of taxonomies used to define what can be called a sustainable activity or financial product.

• **The Reserve Bank of New Zealand released its climate strategy in 2018, which is based on three avenues: monitoring and managing its impact on climate, understanding and incorporating the impact of climate change on its core functions, and providing leadership as an institution.**

• **The Office of the Superintendent of Financial Institutions (OSFI), Canada's top financial regulator, considers capital buffers in order to ensure that federally regulated financial institutions can endure an abrupt transition to a green economy.** Existing proposals include the definition of "one-for-one" capital requirements for the funding of new fossil fuel projects, thus requiring banks to fund these projects with own funds. The OSFI will also publish guidelines on climate risk management for banks, pension funds and other regulated institutions that will define supervisory expectations on climate-related risks.

3 Annex - forward-looking metrics

The metrics and targets listed below are aligned with TCFD recommendations and can be found in the most commonly used ESG disclosure frameworks.[36] The metrics are further aligned with the draft of the European Sustainability Reporting Standards (ESRS)[37] developed by the European Financial Reporting Advisory Group (EFRAG). In line with the climate-related exposure-risk framework described in Section 2 of the main report the metrics in the table are classified either as an "exposure" or as a "risk" metric. The description includes a short definition of the metric as well as information on potential comparability issues.

Generally, for metrics that depend on GHG emissions, comparability may be limited by the use of different GHG emissions accounting standards (especially for Scope 3 emissions). Forward-looking metrics also often rely on scenario assumptions, which limits comparability and consistency between disclosures.

Category	Type	Metric	Unit of measure	Description	ESRS draft
GHG emissions	Exposure	Absolute GHG emission targets	MT of CO2e	GHG emissions in absolute terms for a target year (e.g. 2030). Depending on an undertaking's economic sector the allocation of emissions to different scopes is important for the interpretation of the metric. The comparability and consistency of GHG emissions may be limited by different emissions accounting standards (especially Scope 3).	DR E1-3
GHG emissions	Exposure	Relative GHG emission targets	% reduction from base year	GHG emissions for a target year relative to a base year or to a time period average. The selection of the base year may hinder the comparability and meaningfulness of the metric. For example the recalculation of a base year after an undertaking's acquisitions or divestments may be an issue.	DR E1-3

36 The most used climate-related disclosure frameworks are those developed by the Carbon Disclosure Project (CDP), Climate Disclosure Standards Board (CDSB), Global Reporting Initiative (GRI), the International Integrated Reporting Council (IIRC) and the Sustainability Accounting Standards Board (SASB)

37 See in particular **ESRS E1 – climate change**.

GHG emissions	Exposure	GHG emission intensity target	MT of CO2e/ reporting currency	Describes the amount of emissions per unit of revenue or profit. The same denominator and emission scopes are needed to ensure comparability.	DR E1-3
GHG emissions	Exposure	Net zero target	Year	Net zero targets denote the year by which an undertaking plans to be carbon-neutral. A corresponding pathway as well as a division between actual reductions and compensations and carbon capture and storage are needed for the metric to be interpreted meaningfully.	DR E1-3
GHG emissions	Exposure	GHG emission pathway	MT of CO2e/year	An emission path shows GHG emission reduction targets as a table or graphical pathway or trajectory over time, including the contribution of different decarbonisation levers.	DR E1-3
GHG emissions	Exposure	Locked-in GHG emissions	MT of CO2e/year	Locked-in emissions are estimates of future GHG emissions that are likely to be caused by an undertaking's key assets or products sold within their operating lifetime.	DR E1-1
GHG emissions	Exposure	Avoided GHG emissions	MT of CO2e	Avoided emissions are understood as the estimated GHG reductions of an undertaking's products in comparison to other products that fulfil an equivalent function or to a situation where the product does not exist.	DR E1-14
GHG emissions	Exposure	Future portfolio GHG emission intensity	MT of CO2e/ reporting currency	Financial institutions only. Forward-looking estimate of the weighted average carbon intensity of each portfolio over the course of its planning horizon. Reliable emissions data as well as information on the reduction targets of counterparties are needed to ensure the metric's meaningfulness.	DR E1-1

Capital deployment	Exposure	Low-carbon CapEx	Reporting currency	Amount of investment in low-carbon capital assets. If the EU taxonomy applies, the comparability of the metric is ensured.	DR E1-4
Capital deployment	Exposure	Low-carbon OpEx	Reporting currency	Amount of operating expenses for low-carbon products and services. If the EU taxonomy applies, the comparability of the metric is ensured.	DR E1-4
Capital deployment	Exposure	Low-carbon R&D expenses	Reporting currency	Amount of investment in R&D for low-carbon products and services. If the EU taxonomy applies, the comparability of the metric is ensured.	DR E1-4
Capital deployment	Exposure	Low-carbon R&D ratio	%	Percentage of annual revenue invested in R&D of low-carbon products and services. If the EU taxonomy applies, the comparability of the metric is ensured.	DR E1-4
Capital deployment	Exposure	Adaptation /mitigation investment	%, reporting currency	Investment in climate adaptation measures (e.g. soil health, irrigation, technology). If the EU taxonomy applies, the comparability of the metric is ensured.	DR E1-5
Climate-related opportunities	Exposure	Low-carbon revenues	%, reporting currency	Expected revenues from products or services that support the transition to a low-carbon economy.	DR E1-17
Financial impact	Risk	Expected loss due to physical risks	%, reporting currency	Minimum and maximum expected loss from natural catastrophes caused by climate change. Perils include hurricanes, floods, wildfires and droughts. Depending on the physical risk scenario used, the comparability between disclosures may be hindered.	DR E1-15
Financial impact	Risk	Expected loss due to transitional risks	%, Reporting currency	Minimum and maximum expected loss from transitional risks such as policy changes, and demand shocks.	DR E1-16

				Depending on the transitional risk scenario, the comparability between disclosures may be hindered.	
Financial impact	Risk	Climate value-at-risk	Reporting currency	Financial institutions only. Climate VaR aims to assess potential financial sensitivity to climate-related risks and opportunities. Because of its complex estimation methodology and sensitive nature it is not often disclosed. Depending on differences of the applied physical and transitional risk scenarios used, the metric's comparability may be limited.	DR E1-15, E1-16, E1-17
Financial impact	Risk	Unpriced carbon cost	Reporting currency	Difference between what a company pays for carbon today and what it may pay at a given future date based on its sector, and operations, and under different climate change scenarios. Possibility to multiply company emissions by the price per tonne of emissions. This can help understand and manage risks associated with changes in carbon pricing. The omparability of this metrics depends on the choice of underlying climate scenarios or hypotheses.	DR E1-16
Financial impact	Risk	Carbon earnings at-risk	%, reporting currency	Share of the unpriced carbon cost in the company's EBITDA. Comparability may be hampered by the choice of climate scenarios underpinning the unpriced carbon cost and by the type of earnings used (e.g. before vs after tax).	DR E1-16
Physical risks	Exposure	Assets in high physical risk regions	% or reporting currency	Share or value of assets committed in regions likely to become more exposed to acute or chronic physical climate risks over the course of their planning horizon. Comparability will depend on the definition of physical risk, the scenarios and the time horizon considered.	DR E1-15

Physical risks	Exposure	Expected amount of revenue/profits coming from high physical risk locations	%, reporting currency	Metric showing the expected share/value of revenues which will be impacted by future physical hazards such as floods and heatwaves. Comparability will depend on the definition of physical risk, the scenarios and time horizon considered.	DR E1-15
Transition risk	Risk	Shadow/internal carbon price	Price in reporting currency, per MT of CO2e	An internal/shadow price for GHG emissions to estimate the potential impact of external GHG pricing on the profitability of an investment. It can be used to encourage low-carbon investment or deprioritise high-emission projects. Comparability will depend on the climate scenarios and time horizon considered.	DR E1-16
Transition risk	Exposure	Assets exposed to transition risk	%, reporting currency	Forward-looking best estimate of the amount or percentage of carbon-intensive related assets in each portfolio over the course of their planning horizon. Comparability will depend on the climate scenarios and time horizon considered, as well as the definition of carbon-intensive assets.	DR E1-16
Transition risk	Exposure	Energy efficiency target	KJ / Mtoe, % or reporting currency	Quantifiable goal in terms of primary/final energy consumption or production by a specific date. Comparability will depend on the time horizon considered, as well as on the nature of the energy efficiency target.	DR E1-5, E1-6
Transition risk	Exposure	Renewable energy consumption and/or production target	KJ/Mtoe, % or reporting currency	Quantifiable goal in terms of the value or share of renewable energy consumption by a specific date. Comparability will depend on the time horizon considered, as well as the nature of the energy efficiency target.	DR E1-5
Portfolio alignment	Exposure	Emissions over/under a	%, MT of CO2e/year	Amount of apportioned emissions over/under a 1.5°C alignment trajectory in absolute or relative terms. The	DR E1-3

		1.5°C alignment trajectory		comparability of the metric depends on the applied climate scenario and sector-specific pathways.	
Portfolio alignment	Exposure	Binary Target Measurement	%	Financial institutions only. Measures the alignment of a portfolio with a given climate outcome based on the percentage of investments or counterparties in said portfolio with declared net zero/Paris-aligned targets. The comparability of the metric depends on the applied climate scenario and sector-specific pathways, and on the target used.	DR E1-1
Portfolio alignment	Exposure	Benchmark Divergence Models	%, MT of CO2e/year	Measures portfolio alignment at an individual counterparty level by constructing normative benchmarks (emissions pathways that describe what must be done to achieve a given warming target) from forward-looking climate scenarios and comparing counterparty emissions against them.	DR E1-1
Portfolio alignment	Exposure	Implied temperature rise (ITR) models, or portfolio warming potential	Degree Celsius	Temperature value estimates to assess which climate change scenario the company's activities or investment portfolio are currently aligned with. ITR tools allow financial organisations to translate the degree of alignment or misalignment of a given organisation with a benchmark into consequences for a desired climate goal.	DR E1-1

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