



CLIMATE CHANGE STRESS TESTING

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Prepared for the course
**Macro-Prudential Policy: Implementing the
Financial Stability Mandate**

CENTRAL BANKING

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1 **Climate change: some facts**

2 **Climate change and financial stability**

3 **Stress testing and scenario design**

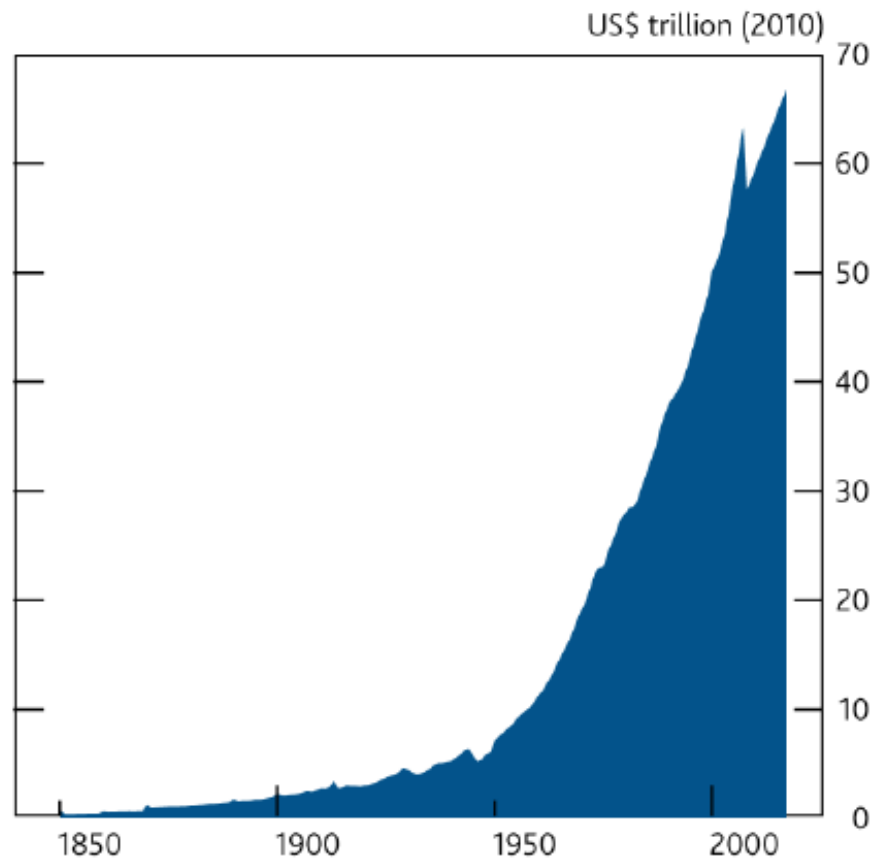
4 **Capital stress tests vs climate change stress tests**

5 **Case studies**

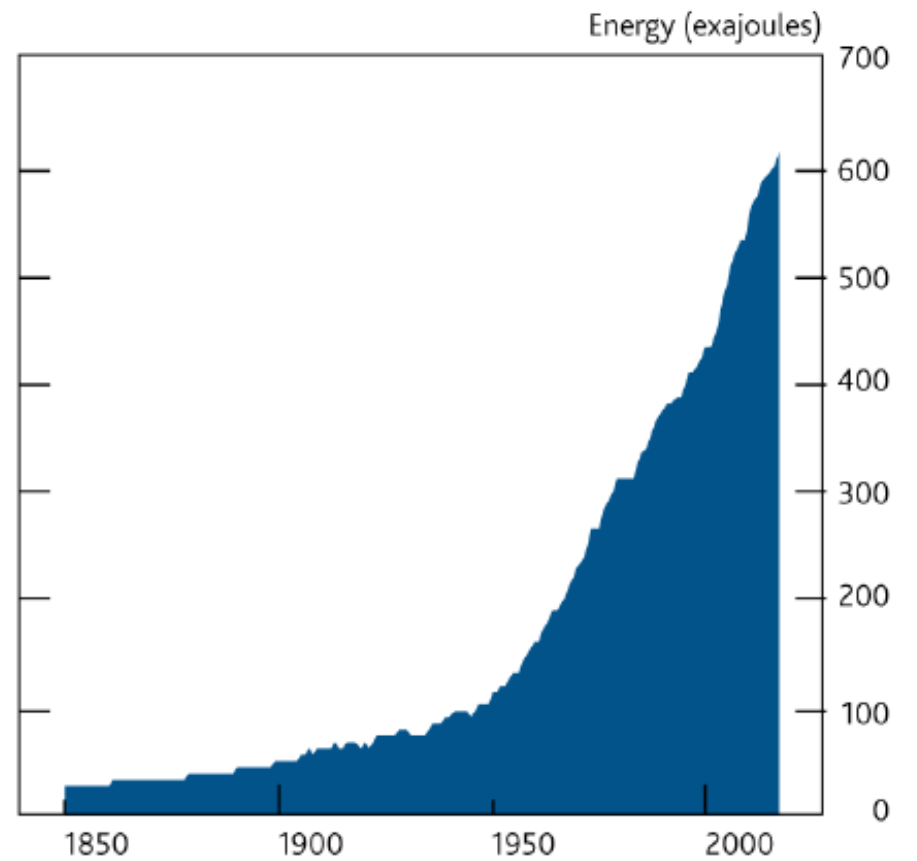
6 **Policy implications**

1. CLIMATE CHANGE: SOME FACTS

Global GDP
A hundredfold increase

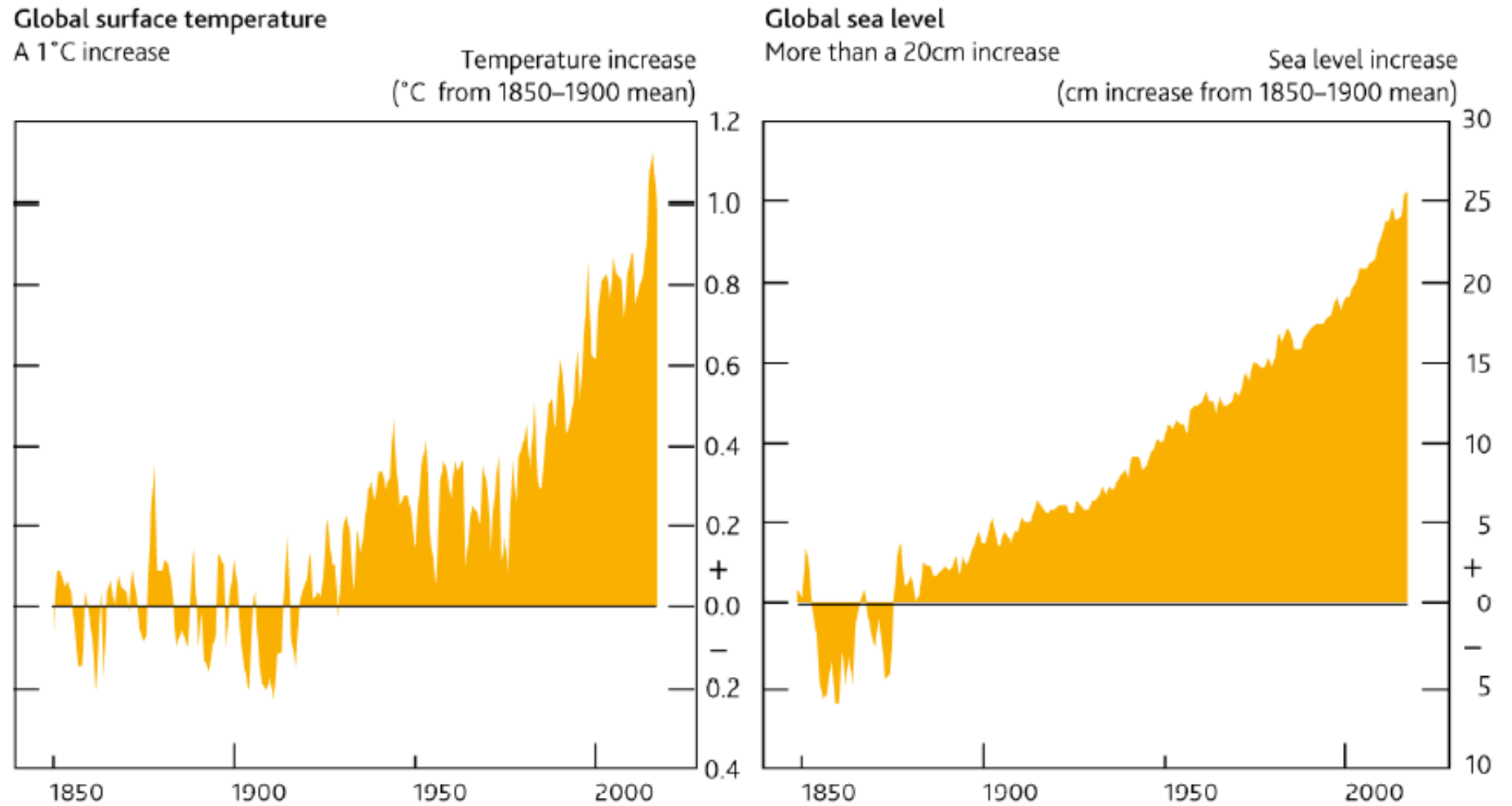


Global energy use
A twentyfold increase



Source: *Transition in thinking: The impact of climate change on the UK banking sector*, Bank of England, September 2018.

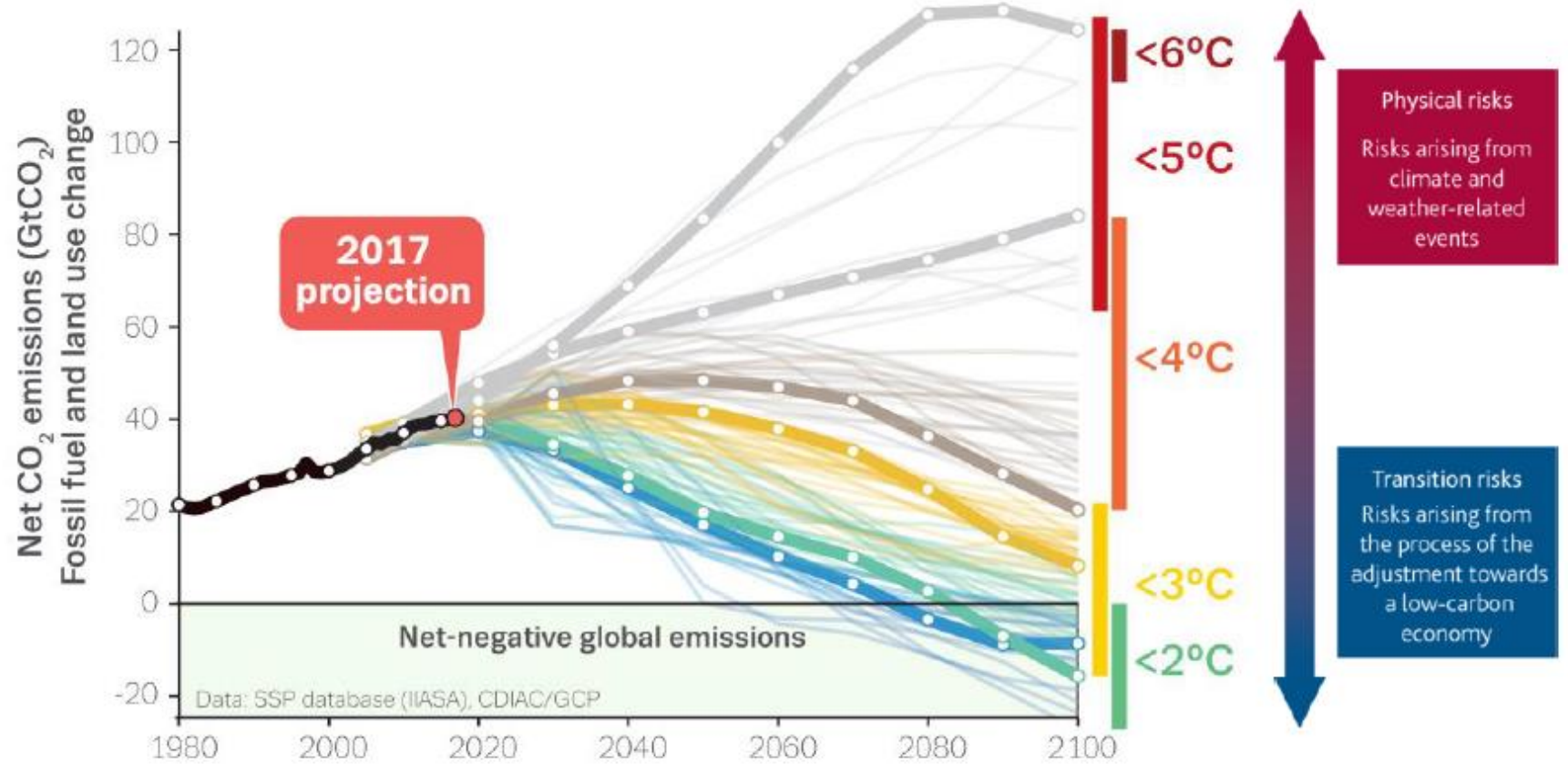
1. CLIMATE CHANGE: SOME FACTS



Source: *Transition in thinking: The impact of climate change on the UK banking sector*, Bank of England, September 2018.

1. CLIMATE CHANGE: SOME FACTS

Chart 1: Possible carbon emission pathways and climate-related risk factors



Source: *Transition in thinking: The impact of climate change on the UK banking sector*, Bank of England, September 2018.

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2. CLIMATE CHANGE AND FINANCIAL STABILITY

FINANCIAL RISKS STEMMING FROM CLIMATE CHANGE:

Physical risk

Transition risk

Litigation risk

TRANSMISSION AND AMPLIFICATION MECHANISMS

Changes in the pricing and management of financial risks

Potential for pro-cyclical behavior by market participants

Self-reinforcing reductions in bank lending and insurance provision

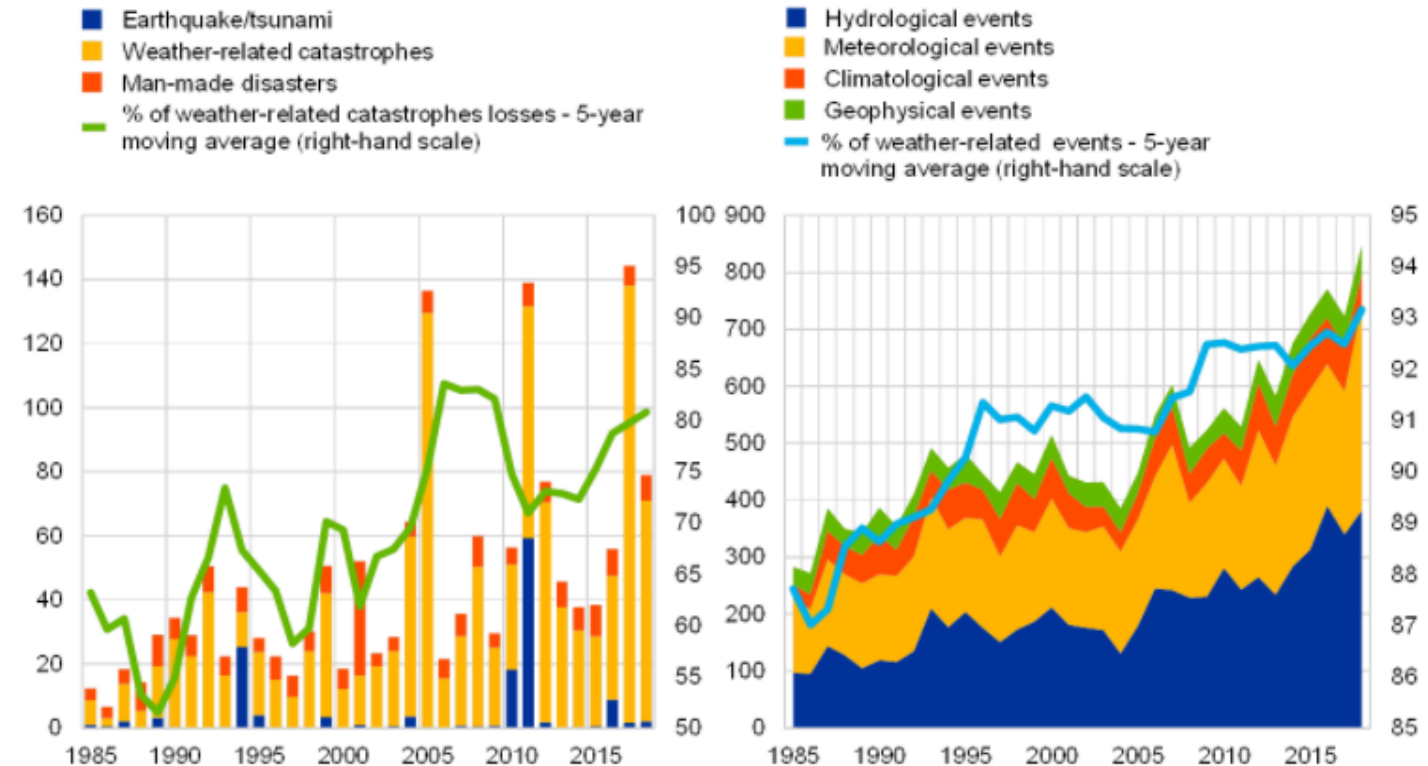
Source: *The Implications of Climate Change for Financial Stability*, Financial Stability Board, 23 November 2020

2. CLIMATE CHANGE AND FINANCIAL STABILITY

Physical risk: weather-related insured losses and the number of natural loss events are increasing

Global insured catastrophe losses (left panel) and number of relevant natural loss events worldwide (right panel)

(1985-2018; left panel: left-hand scale: USD billions; right-hand scale: percentages; right panel: left-hand scale: number of events; right-hand scale: percentages)

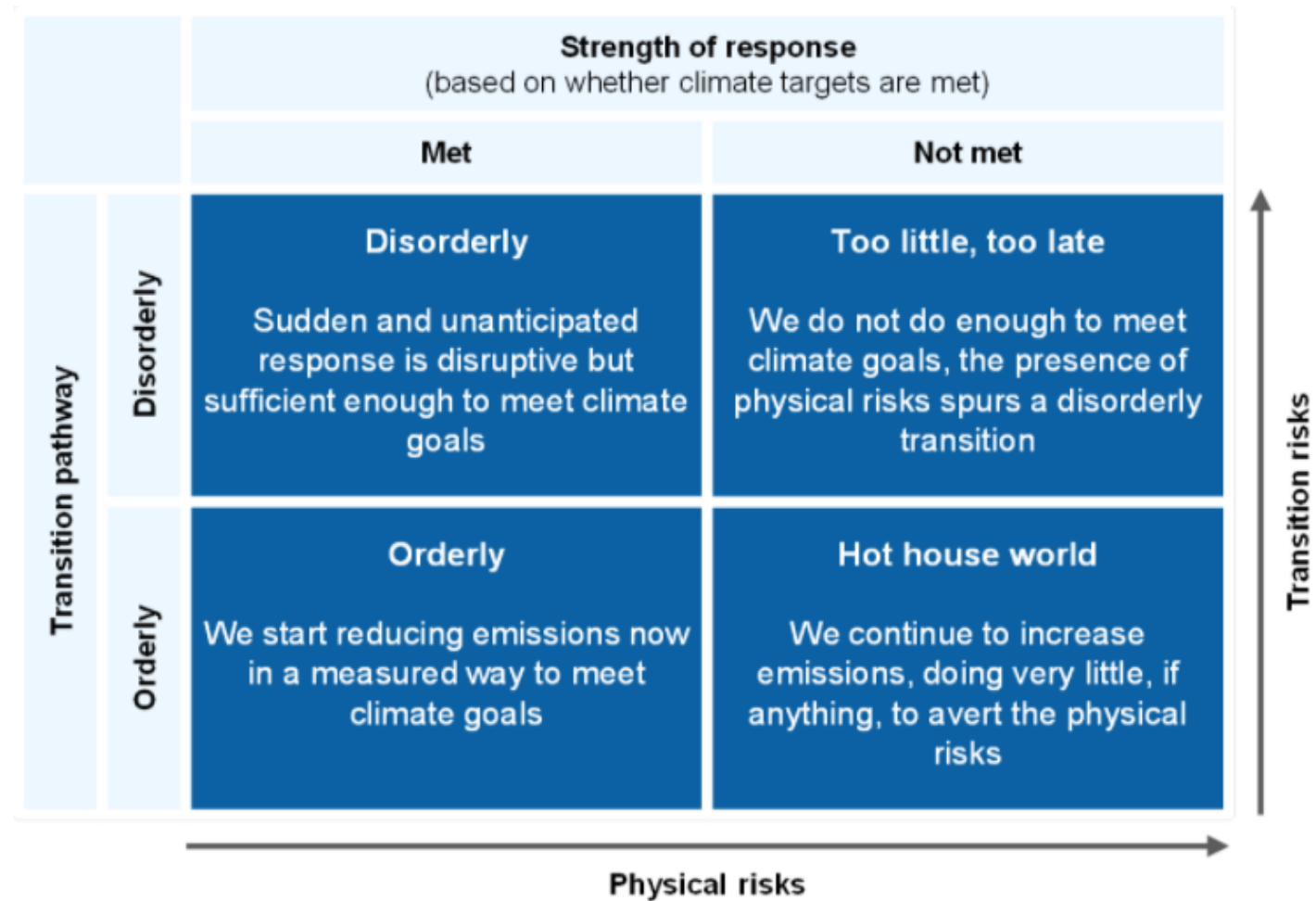


Sources: Swiss Re Institute, Munich Re NatCatService and ECB calculations.

Source: *Climate change and financial stability*, Giuzio, M. et al (2019), Financial Stability Review, ECB, May 2019

2. CLIMATE CHANGE AND FINANCIAL STABILITY

Physical versus transition risks: temperature scenarios and the cost of climate change



Source: NGFS (2019), op. cit.

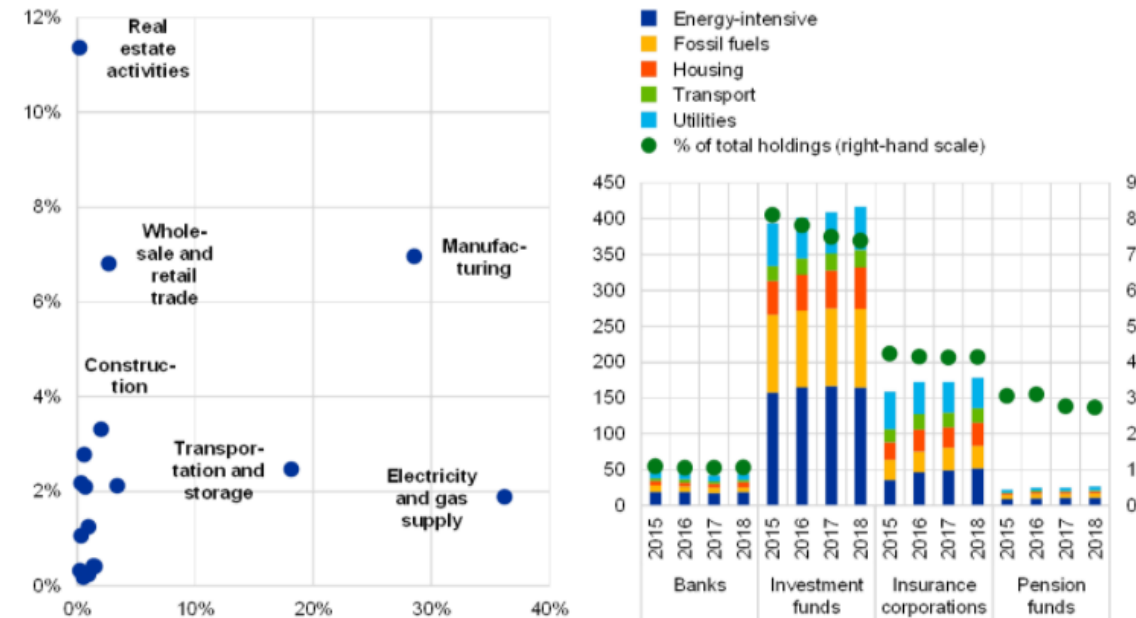
Source: *Climate change and financial stability*, Giuzio, M. et al (2019), Financial Stability Review, ECB, May 2019

2. CLIMATE CHANGE AND FINANCIAL STABILITY

Sectoral exposure statistics can provide a first comprehensive approximation of transition risk

Euro area banks' exposures and sectoral contributions to carbon emissions (left panel); evolution of investment exposures to climate-sensitive sectors (by issuer sector) (right panel)

(left panel: percentages; x-axis: sectoral contributions to total carbon emissions; y-axis: bank exposures (as a share of total exposures); right panel: Dec. 2015-Dec. 2018; left-hand scale: € billions; right-hand scale: percentage of total holdings)



Sources: ECB supervisory statistics, European Commission EDGAR dataset, Eurostat, ECB SHSS, ECB CSDB and ECB calculations. Notes: Left panel: the share of carbon emissions is calculated from Eurostat data on air emissions accounts by NACE activity, which cover the EU28, Turkey and Serbia. Electricity and gas supply also includes steam and air conditioning supply. Right panel: the classification of climate-sensitive assets follows the approach of Battiston et al. (2017). Sectoral holdings are classified according to the NACE categorisation in the ECB's Centralised Securities Database (CSDB).

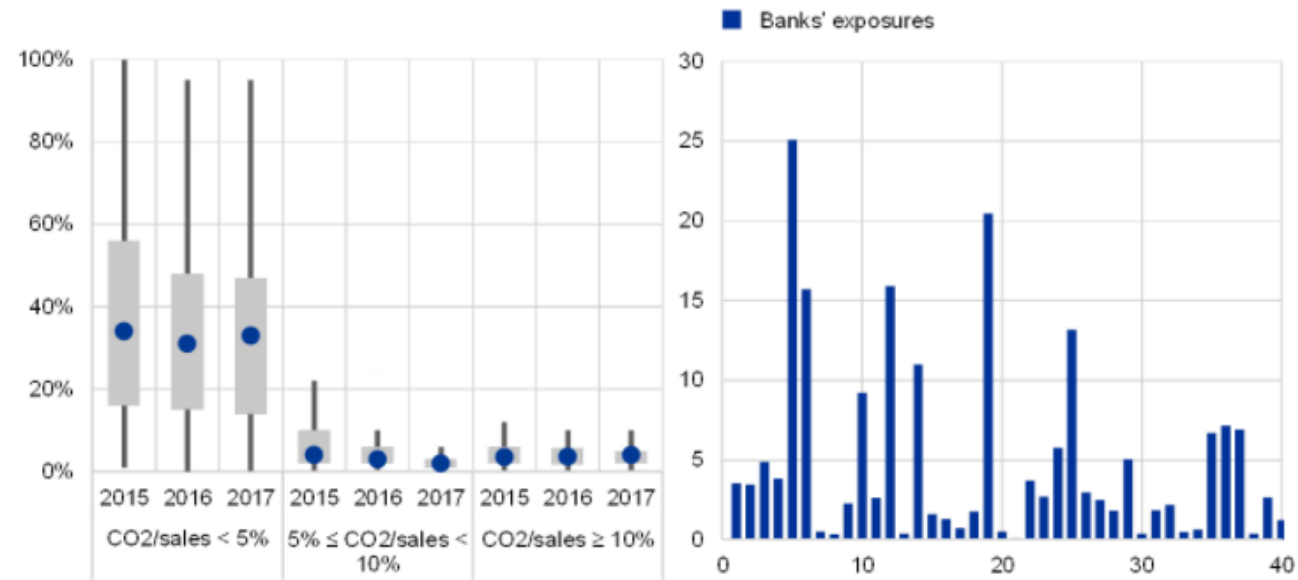
Source: *Climate change and financial stability*, Giuzio, M. et al (2019), Financial Stability Review, ECB, May 2019

2. CLIMATE CHANGE AND FINANCIAL STABILITY

Although the relative carbon intensity of exposures appears moderate for the sample, absolute exposures to large emitters could still be significant

Distribution of large exposures of banks in the sample to firms with different carbon intensities (as a share of total large exposures) (left panel); banks' exposures to the reporting 40 firms with the highest carbon emissions (right panel)

(left panel: median, quartiles and 10th and 90th percentiles; right panel: € billions)

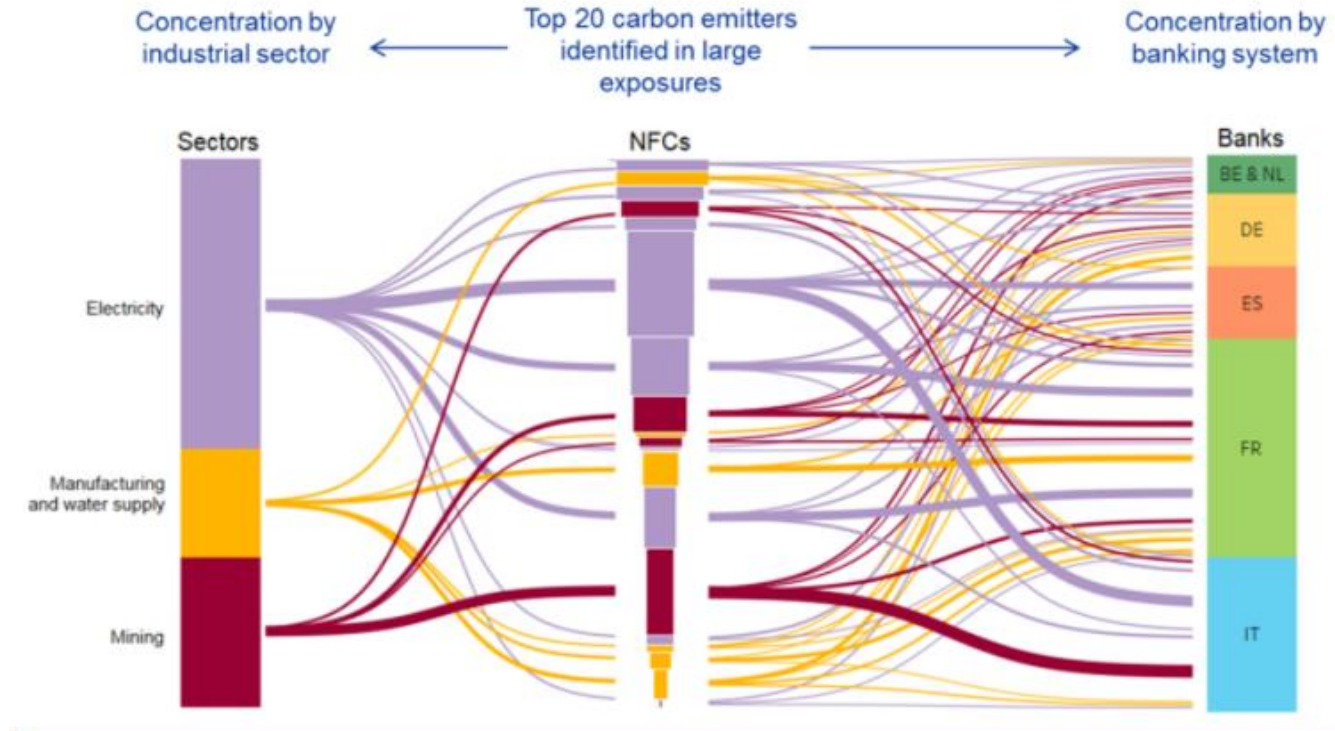


Sources: Thomson Reuters, ECB supervisory statistics (large exposures) and ECB calculations. Notes: Carbon intensity is calculated as the ratio of a firm's total carbon emissions to its total sales. Altogether, 76% of the firms in the sample belong to the most carbon-efficient group (carbon emissions/sales < 5%), 9% to the mid-range, and 15% to the most carbon-intensive group. The carbon emissions refer to Scope 2 emissions (emissions arising from purchased energy, heat or steam consumed by the firm). The carbon accounting standard has been developed and made available by the Greenhouse Gas Protocol and the Carbon Disclosure Project.

2. CLIMATE CHANGE AND FINANCIAL STABILITY

Large exposures to reporting firms with the highest emissions

Euro area banks' large exposures to reporting firms with the highest carbon emissions
(share of total loans)



Sources: Thomson Reuters, ECB supervisory statistics (large exposures) and ECB calculations. Notes: The top 20 carbon-emitting companies reported in the large exposures dataset. The companies are ranked in descending order according to their total carbon emissions over the last four years (middle bar); the height of the NFCs' rectangles represents total loans extended to the respective company, whereas the width of the rectangles represents the carbon emissions of the company. The NFCs are classified according to the NACE categorisation (left bar). The banking systems column includes 29 banks (right bar).

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3. STRESS TESTING AND SCENARIO DESIGN

IDENTIFYING OBJECTIVES AND MATERIAL RISKS

Table 1. **Examples of how central banks and supervisors assess different risks**

	Objective	Types of risk assessment	Useful for
A	Assess financial firm-specific risks	Stress testing, challenging firm capital adequacy assessments	Microprudential policy Identifying risks related to safety and soundness
B	Assess financial system-wide risks	Stress testing, research on individual transmission channels	Macroprudential policy Identifying systemic risks and macroeconomic impacts
C	Assess macroeconomic impacts	Macroeconomic forecasting, research on structural changes	Understanding macroeconomic outlook Monetary policy
D	Assess risks to own balance sheet	Credit and market risk analysis, stress testing	Managing risks to own operations TCFD disclosures

Source: *Guide to climate scenario analysis for central banks and supervisors*, Network for Greening the Financial System, June 2020

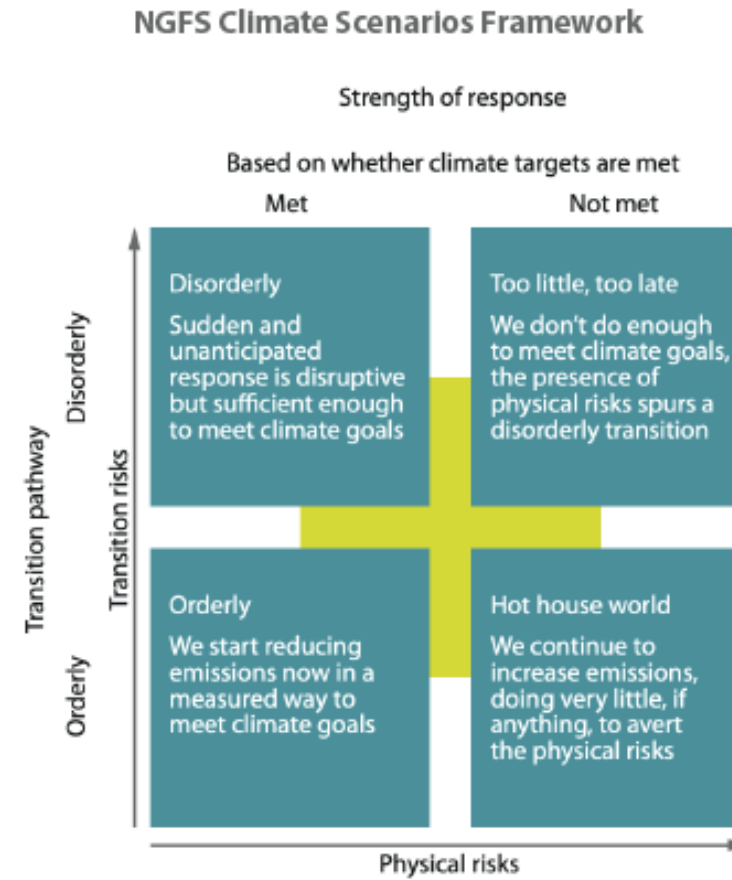
KEY FEATURES

- Multiple climate scenarios
- Broader inclusion of participants (both banks and insurers)
- Extended modelling horizon (30-years)
- Integrated climate and macrofinancial variables
- Counterparty-level modelling expectations
- [- Detailed sectorial and geographic granularity]

Source: The 2021 biennial exploratory scenario on the financial risks from climate change, Bank of England, December 2019

3. STRESS TESTING AND SCENARIO DESIGN

SCENARIO DESIGN

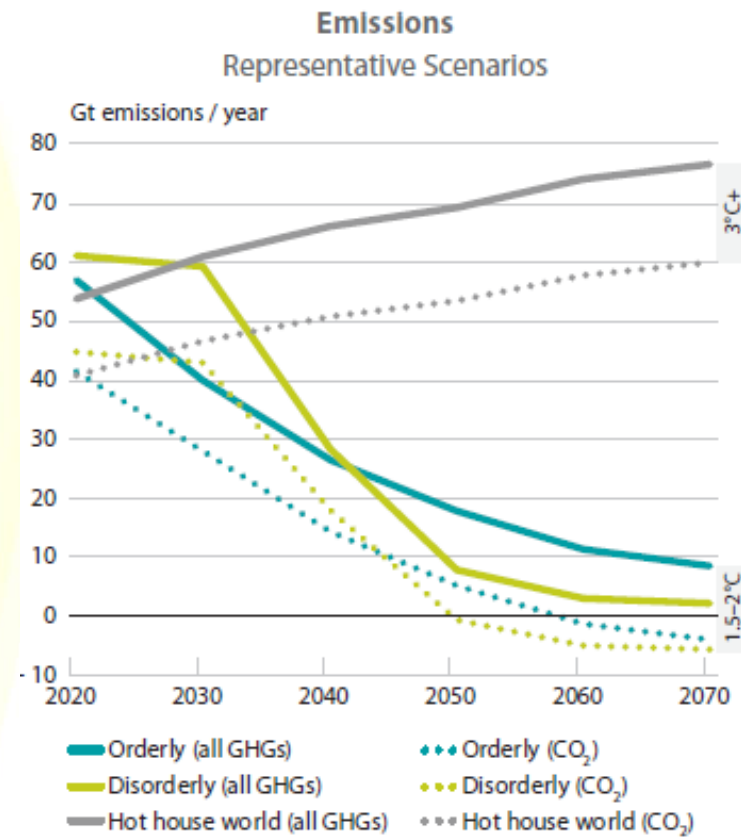


Source: NGFS (2019a).

Source: *NGFS Climate Scenarios for central banks and supervisors*, Network for Greening the Financial System, June 2020

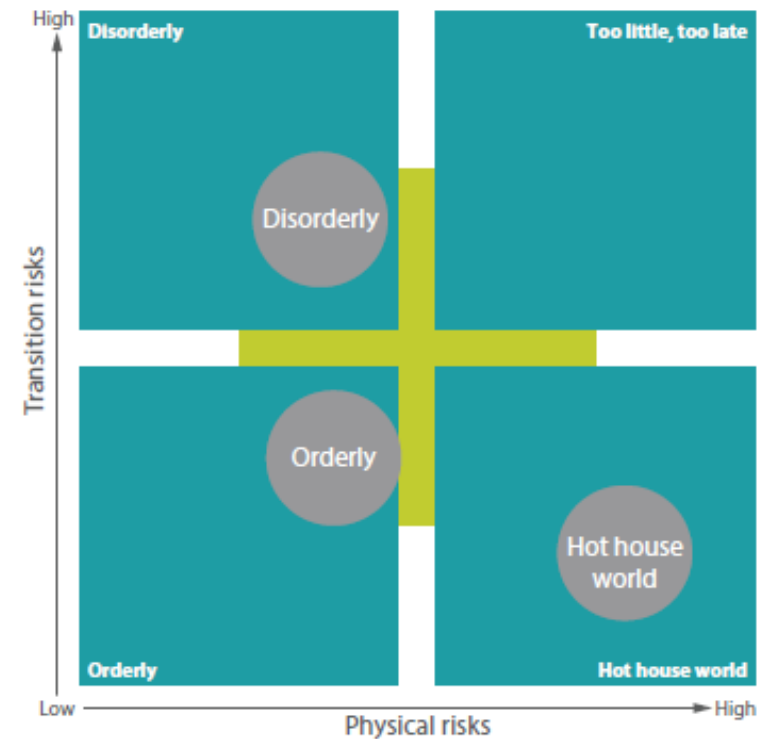
3. STRESS TESTING AND SCENARIO DESIGN

SCENARIO DESIGN



Source: IIASA NGFS Climate Scenarios Database, using marker models.

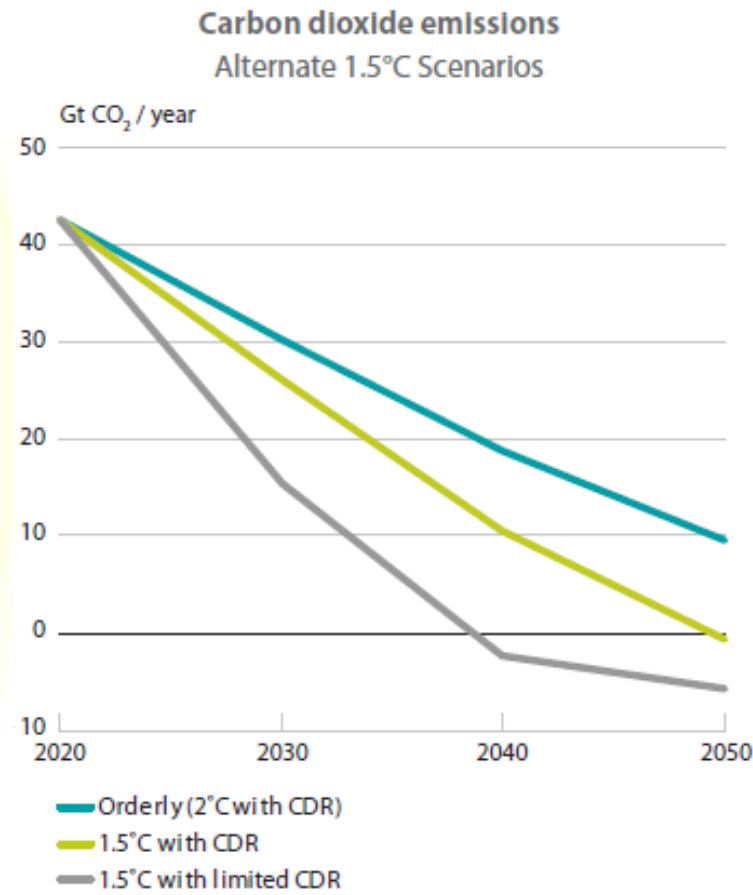
Mapping of the representative scenarios to the Framework



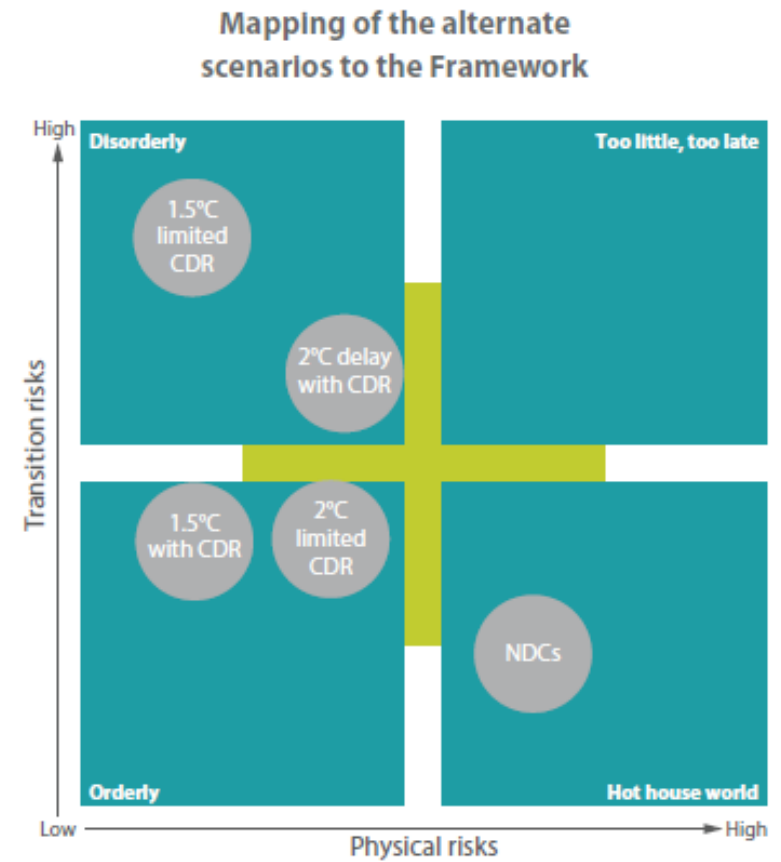
Source: NGFS Climate Scenarios for central banks and supervisors, Network for Greening the Financial System, June 2020

3. STRESS TESTING AND SCENARIO DESIGN

SCENARIO DESIGN



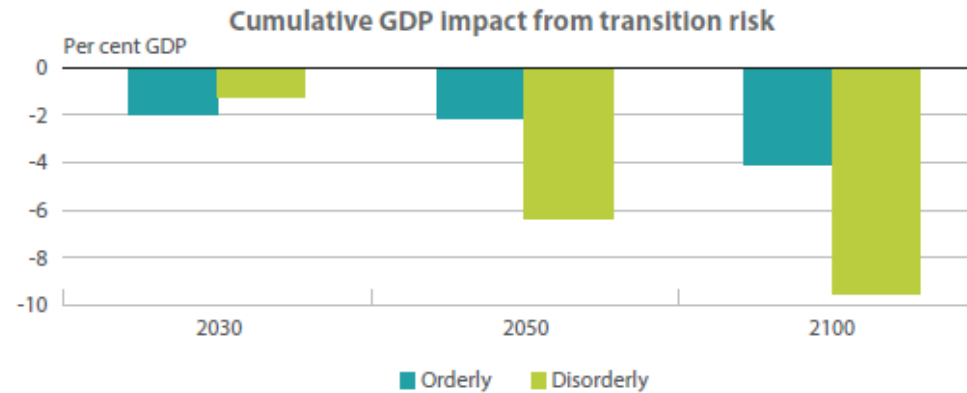
Source: IIASA NGFS Climate Scenarios Database, REMIND model.



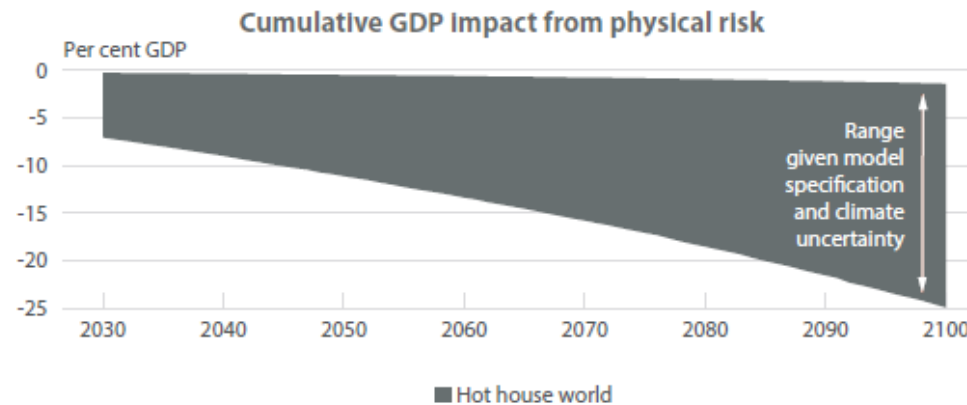
Source: NGFS Climate Scenarios for central banks and supervisors, Network for Greening the Financial System, June 2020

3. STRESS TESTING AND SCENARIO DESIGN

SCENARIO DESIGN



Source: IIASA NGFS Climate Scenarios Portal, marker models.



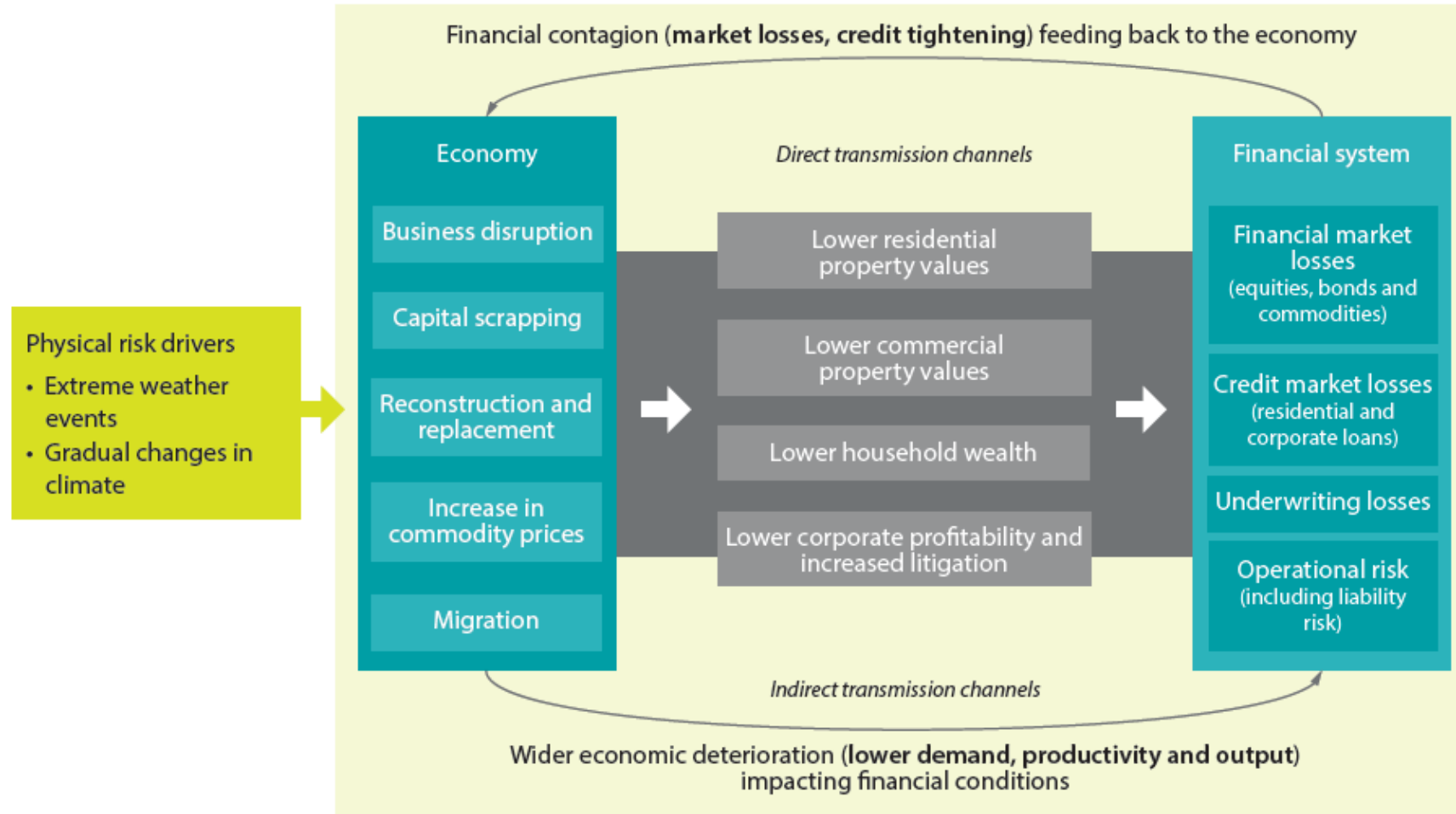
Source: PIK calculations based on damage function model specifications from the wider literature. See slide 29 for further details.

Source: *NGFS Climate Scenarios for central banks and supervisors*, Network for Greening the Financial System, June 2020

3. STRESS TESTING AND SCENARIO DESIGN

ASSESSING FINANCIAL STABILITY RISKS: TRANSMISSION CHANNELS

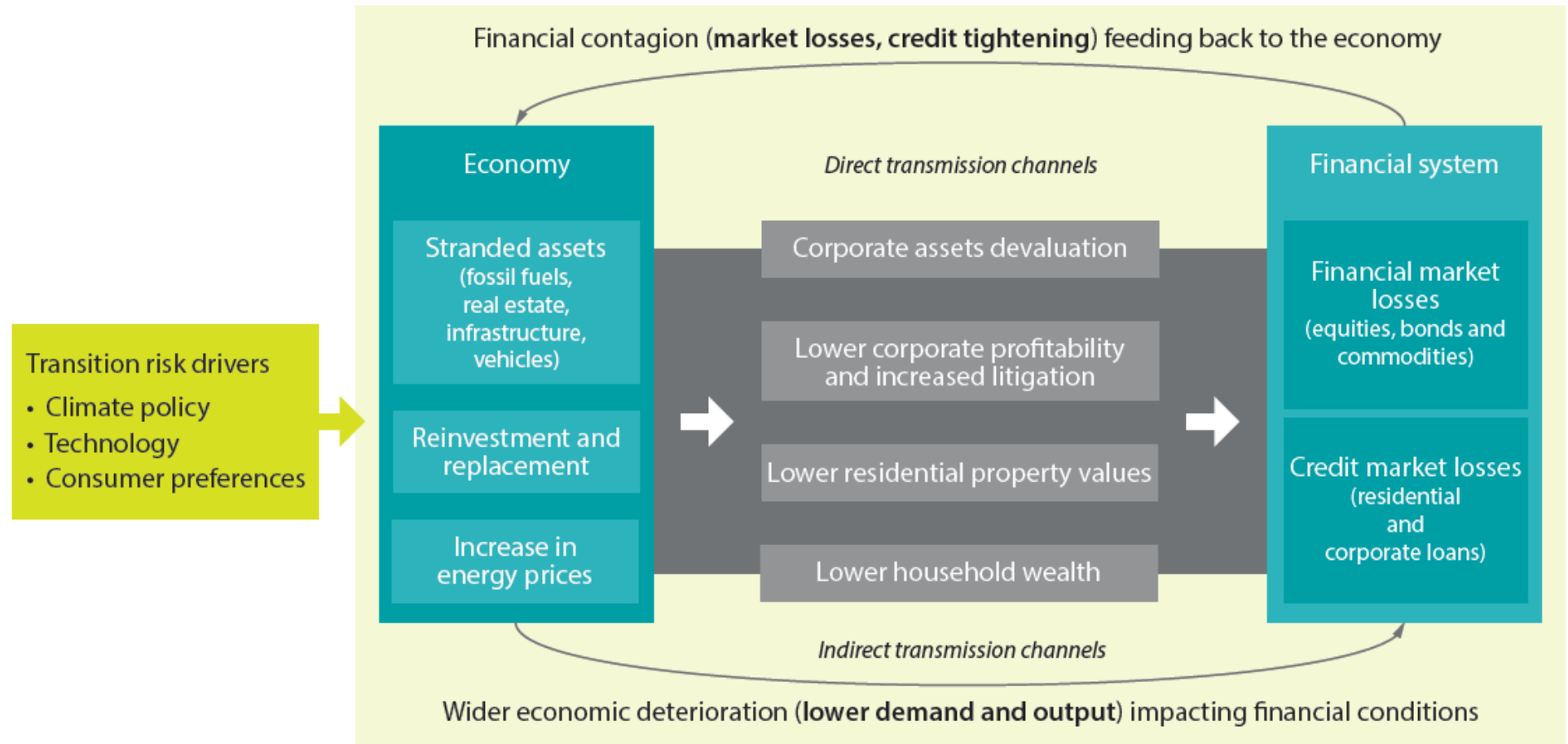
Figure 1 From physical risk to financial stability risks



3. STRESS TESTING AND SCENARIO DESIGN

ASSESSING FINANCIAL STABILITY RISKS: TRANSMISSION CHANNELS

Figure 2 From transition risk to financial stability risks



3. STRESS TESTING AND SCENARIO DESIGN

DESIRED OUTCOMES

- Quantify the financial exposures of participating firms and, more broadly, the financial system to climate-related risks
- Identify and understand the challenges to participants' business models from climate-related risks, gauge their likely responses and the implications for the provision of financial services
- Assist participants in enhancing their management of climate-related risks

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4. CAPITAL STRESS TESTS VS CLIMATE CHANGE STRESS TESTS

KEY DIFFERENCES

- Lack of historical data challenges the modeling of the interactions between climate, the real economy and the financial sector
- Lack of historical data on the relationship between credit risk and credit losses
- Climate stress testing has a much longer time horizon (30 to 50 years)
- Climate stress testing require much more granular data (sectorial and geographic expositions)
- Much larger uncertainty associated with market participants' actions on equilibrium prices and aggregate outcomes

Source: "Challenges in Stress testing and Climate Change", Covas, F., Bank Policy Institute, October 2020

4. CAPITAL STRESS TESTS VS CLIMATE CHANGE STRESS TESTS

Design	Supervisory U.S. Stress Tests	Climate Change Stress Testing
Planning horizon	<p>Nine quarters.</p> <ul style="list-style-type: none"> Tradeoff between capturing the full extent of losses that might be incurred on assets originated when underwriting standards were looser, and <u>a reasonable ability to project with some degree of confidence the losses and resources at more distant future points.</u> 	<p>Varies; most common is between 30 and 50 years.</p> <ul style="list-style-type: none"> Climate risks and the policies to mitigate them have long time horizons. Longer horizons increase the materiality of climate change risks, but also lead to more uncertainty in loss projections.
Number and granularity of scenarios	<p>One severely adverse stress scenario combined with a global market shock for banks with significant trading exposures.</p> <ul style="list-style-type: none"> The stress scenario has typically mimicked the behavior of series in the 2007–2009 financial crisis. Macroeconomic scenarios (16 domestic macro series, 9 foreign series). Global market shock (+20K factor shocks). 	<p>Between 3 and 5 scenarios.</p> <p>Climate change variables:</p> <ul style="list-style-type: none"> Physical risks Transition risks <p>Macrofinancial variables:</p> <ul style="list-style-type: none"> Standard series embedded in stress tests. Scenarios revolve around policies to mitigate greenhouse gas emissions and the pace of technological breakthroughs. Very challenging to model the interactions between and among climate, the macroeconomy, and the financial sector. Much less historical data to rely on to assess the severity of the scenario.

4. CAPITAL STRESS TESTS VS CLIMATE CHANGE STRESS TESTS

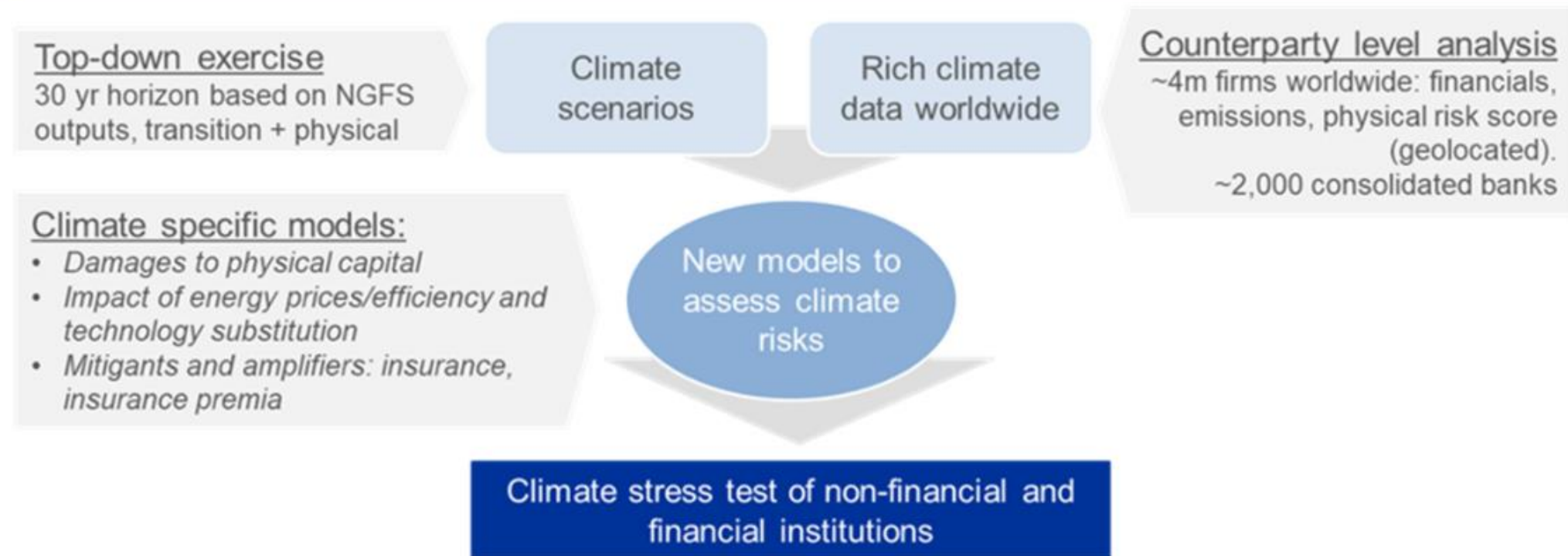
Design	Supervisory U.S. Stress Tests	Climate Change Stress Testing
Data and Models	<ul style="list-style-type: none"> • Large amounts of historical data on losses and revenues. • Projections use a mix of bottom-up and top-down models. • Loan losses: PD/LGD/EAD models. • Trading losses: applies risk-factor shocks to exposures. • Operational risk: models that relate operational risk losses with economic conditions. • Pre-provision net revenue: models that relate specific profit components with firm characteristics and macroeconomic variables. 	<ul style="list-style-type: none"> • Large data gaps; lack of historical data. • Most promising approaches are focused on the adjustment of probability of default and loss given default using the PD/LGD/EAD framework. • Long horizon requires large amount of information about counterparty behavior to model PD and LGD. Data on small firms are typically not available. • Lack of data is addressed using less reliable models or overlays. • The data on climate change scenarios need to be highly granular so that banks can effectively assess borrower-level risks. • Potential double counting the impact of climate change on asset prices and credit losses.
Bank Behavior over the Stress Horizon	<ul style="list-style-type: none"> • Bank balance sheets remain constant over the stress horizon. • It is a conservative assumption, because loan demand falls in recessions, but this is ameliorated due to the relatively short time horizon. 	<ul style="list-style-type: none"> • Bank balance sheets remain constant over the stress horizon. • Given the long horizon, it is highly unrealistic to assume a static balance sheet over the stress horizon. • The ACPR pilot climate exercise includes a dynamic balance sheet between 2025 and 2050.

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CASE STUDY: ECB

Chart 1

Innovative components of the ECB climate stress test

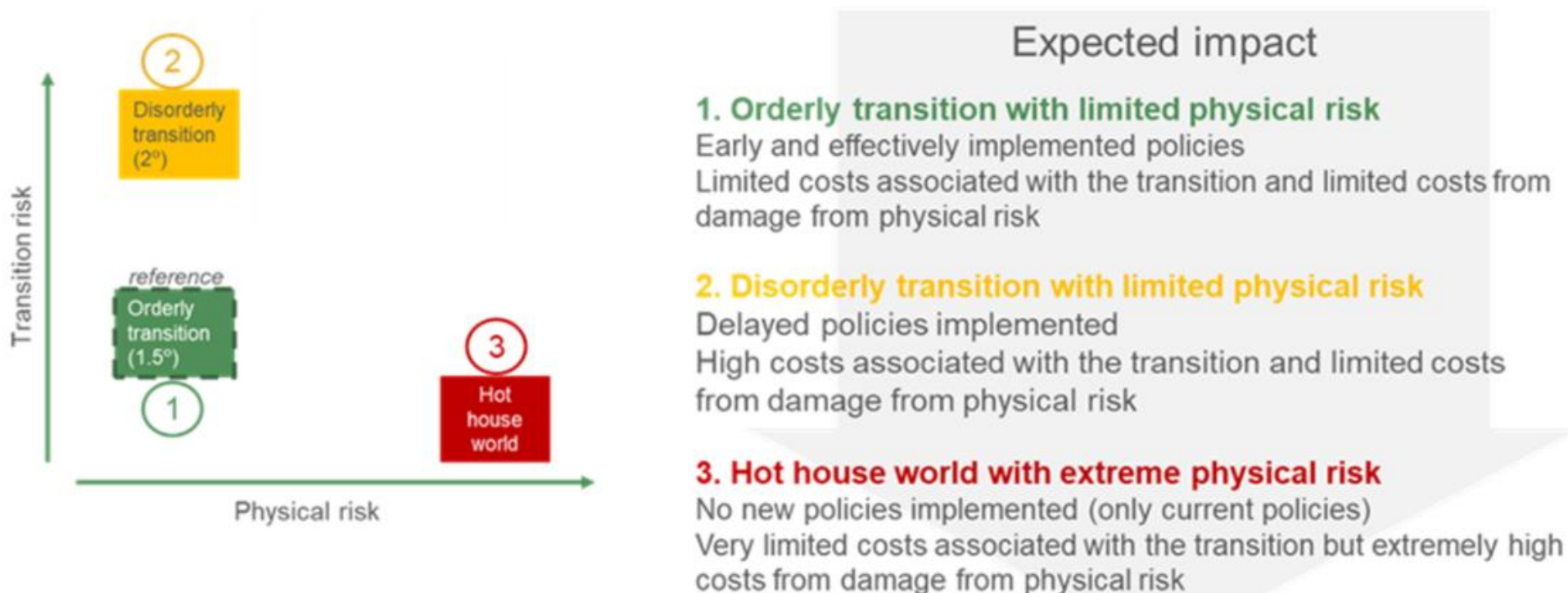


Source: ECB

CASE STUDY: ECB

Chart 3

ECB climate scenarios

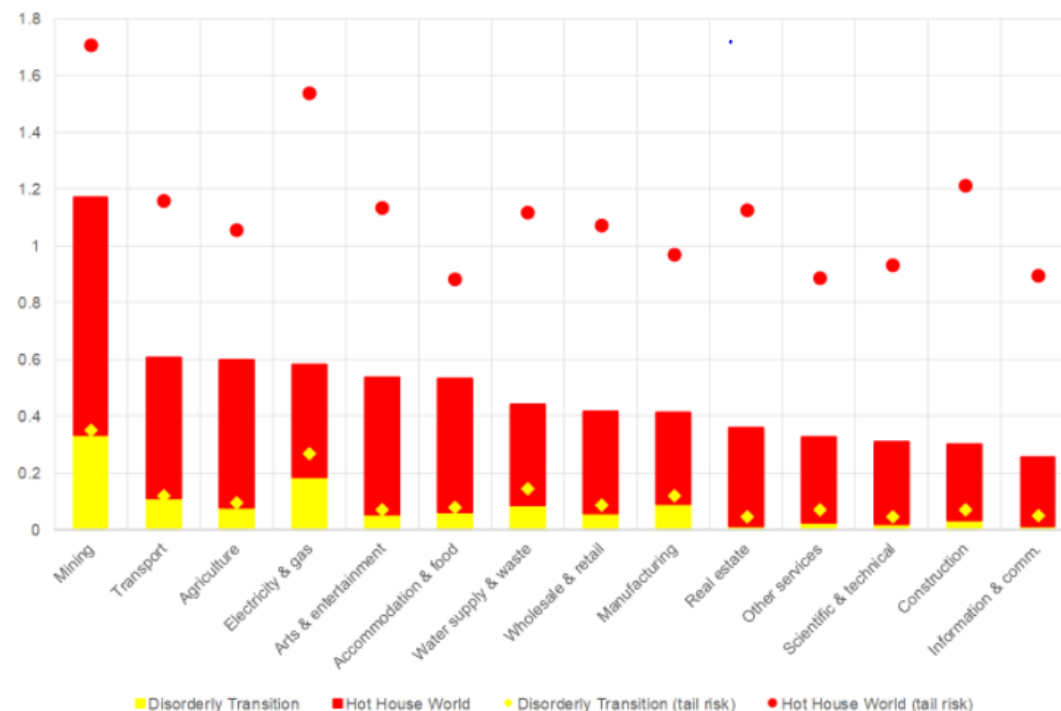


Source: ECB

CASE STUDY: ECB

Figure 4

Differences in firms' default probabilities (%) in the two adverse scenarios with respect to the orderly transition scenario, by sector and group of firms (mean firms, and firms mostly exposed to physical risk)



Source: ECB calculations

Note: the bars represent the median changes in default probabilities over the next 30 years; the dots instead report the changes in default probabilities when considering the firms that are most exposed to physical risk (95th percentile based on firms' physical risk score).

Source: *Shining a light on climate risks: the ECB's economy-wide climate stress test*, Blog post by Luis de Guindos, Vice-President of the ECB, 18 March 2021

CASE STUDY: EIOPA

Table 1-2 Overview of main transmission channels for climate change-related risks

Type of risk	Transmission channel	Balance sheet impact	Example	Covered in this paper?
Physical risk	Underwriting risk	Liabilities	Higher than expected insurance claims on damaged insured assets (non-life) or higher than expected mortality or morbidity rates (life/health)	Yes
	Market risk	Assets	Impairing of asset values due to financial losses affecting profitability of firms, due to for instance business interruptions, or damage to real estate. Specific example: equity price shocks	Yes
	Credit risk	Assets	Deteriorating creditworthiness of borrowers/bonds/counterparties/reinsurers due to financial losses stemming from climate change Specific example: bond price/yield shock	Yes
	Operational risk	Assets	Disruption of own insurance activities and/or assets, such as damage to own property	No
	Liquidity risk ⁹	Assets / Liabilities	Unexpected higher payouts and/or lapses as broader economic environment deteriorates	No (not as part of climate ST)

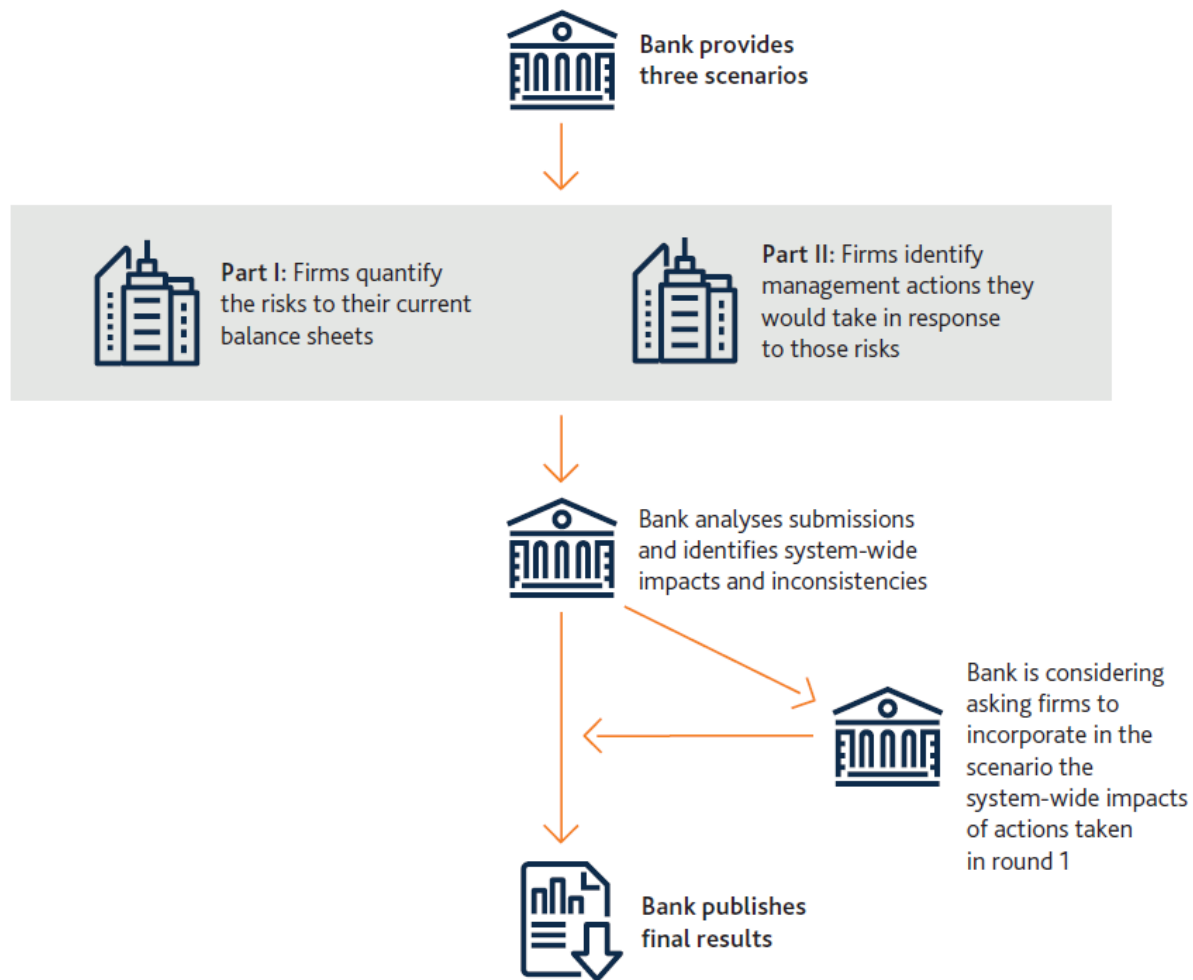
CASE STUDY: EIOPA

Table 1-2 Overview of main transmission channels for climate change-related risks

Type of risk	Transmission channel	Balance sheet impact	Example	Covered in this paper?
Transition risk	Market risk	Assets	Impairment of financial asset values due to low-carbon transition, for instance stranded assets, 'brown' real estate and/or decrease in value of carbon/GHG intensive sectors. Specific example: equity price shock	Yes
	Credit risk	Assets	Deteriorating creditworthiness of borrowers/bonds/counterparties as entities that fail to properly address transition risk may suffer losses Specific example: bond price/yield shock	Yes
	Underwriting risk	Liabilities	Decrease of underwriting business due to increase of insurance prices in response to higher than expected insurance claims (non-life) or changes in policyholders' expectations and behavior related to sustainability factors (e.g. green reputation) (life)	No
Legal liability risk	Underwriting risk	Liabilities	Higher than expected claims on professional indemnity cover, as parties are held accountable for losses related to environmental damages caused by their activities	No
	Legal/reputational risk	Assets/ Liabilities	Insurers could be held responsible for climate change and/or not doing enough to mitigate/adapt	No

CASE STUDY: BANK OF ENGLAND

Figure 2.1 Overview of the 2021 BES exercise



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Table A.2

Recommendations by the NGFS and European initiatives with a focus on financial stability

	2019 NGFS Recommendations	2018 EU Action Plan and regulatory proposals & ESRB proposals
Monitoring climate-related risks	Central banks and supervisors are encouraged to develop methodologies for measuring climate-related risks, including forward-looking scenario analysis and stress tests	The ESRB has proposed that the European Supervisory Authorities include climate risk scenarios in stress-test exercises, and is conducting analytical work on data and methodologies
Developing taxonomies	Regulators should develop taxonomies that aim to facilitate (i) financial institutions' climate risk management, (ii) assessment of the potential risk differentials between green and brown assets, and (iii) mobilisation of capital for green investments	The Commission has proposed a regulation for an EU classification system of sustainable economic activity (taxonomy) , which aims to help investors redirect capital towards green activities. This feeds into a Green Bond Standard and disclosure requirements, and could potentially be used in the context of low-carbon benchmarks and a "green supporting factor"
Promoting disclosures	Non-financial and financial institutions should adopt the FSB TCFD disclosure recommendations	The Commission has proposed a disclosure regulation and a regulation for a low-carbon benchmark and a positive carbon impact benchmark
Incorporating climate-related risks into prudential frameworks	Central banks and supervisors are encouraged to integrate climate-related risks into supervision, among other things, by (i) raising awareness and promoting climate risk assessment among institutions, (ii) setting supervisory expectations regarding governance and risk management, and (iii) potentially considering integrating climate risk into the prudential framework	In its Action Plan, the Commission states that it will explore the feasibility of the inclusion of climate risks in institutions' risk management policies and the potential calibration of capital requirements for banks as part of the CRR/CRD.

Supervisory expectations relating to business model and strategy

Expectation 1: Institutions are expected to understand the impact of climate-related and environmental risks on the business environment in which they operate, in the short, medium and long term, in order to be able to make informed strategic and business decisions

Expectation 2: When determining and implementing their business strategy, institutions are expected to integrate climate-related and environmental risks that impact their business environment in the short, medium or long term

Supervisory expectations relating to governance and risk appetite

Expectation 3: The management body is expected to consider climate-related and environmental risks when developing the institution's overall business strategy, business objectives and risk management framework and to exercise effective oversight of climate-related and environmental risks

Expectation 4: Institutions are expected to explicitly include climate-related and environmental risks in their risk appetite framework

Expectation 5: Institutions are expected to assign responsibility for the management of climate-related and environmental risks within the organizational structure in accordance with the three lines of defence model.

Expectation 6: For the purposes of internal reporting, institutions are expected to report aggregated risk data that reflect their exposures to climate-related and environmental risks with a view to enabling the management body and relevant sub-committees to make informed decisions

Supervisory expectations relating to risk management

Expectation 7: Institutions are expected to incorporate climate-related and environmental risks as drivers of existing risk categories into their risk management framework, with a view to managing, monitoring and mitigating these over a sufficiently long-term horizon, and to review their arrangements on a regular basis. Institutions are expected to identify and quantify these risks within their overall process of ensuring capital adequacy.

Expectation 8: In their credit risk management, institutions are expected to consider climate-related and environmental risks at all relevant stages of the credit-granting process and to monitor the risks in their portfolios.

Expectation 9: Institutions are expected to consider how climate-related and environmental events could have an adverse impact on business continuity and the extent to which the nature on their activities could increase reputational and/or liability risks.

Expectation 10: Institutions are expected to monitor on an ongoing basis the effect of climate-related and environmental factors on their current market risks positions and future investments, and to develop stress tests that incorporate climate-related and environmental risks.

Expectation 11: Institutions with material climate-related and environmental risks are expected to evaluate the appropriateness of their stress testing, with a view to incorporating them into their baseline and adverse scenarios.

Expectation 12: Institutions are expected to assess whether material climate-related and environmental risks could cause net cash outflows or depletion of liquidity buffers and, if so, incorporate these factors into their liquidity risk management and liquidity buffer calibration.

Supervisory expectations relating to disclosures

Expectation 13: For the purposes of their regulatory disclosures, institutions are expected to publish meaningful information and key metrics on climate-related and environmental risks that they deem to be material, with due regard to the European Commission's Guidelines on non-financial reporting: Supplement on reporting climate-related information.



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