Economy-wide climate stress test: methodology and results

European Central Bank

List of abbreviations

Abbreviations	Meaning
BoE	Bank Of England
ECB	European Central Bank
EU	European Union
GHG	Greenhouse gas
NGFS	Network of Central Banks and Supervisors for Greening the Financial System

1 Introduction

Wide - climate stress test background and context

In September 2022, the ECB published the results of the economy-wide climate stress test, from which banks benefit from the early adoption of green policies in order to foster a transition to a sustainable economy

- The ECB published the results of the climate stress test, testing **the impact of climate change on 4 million companies and 1,600 banks in the euro area under three different climate policy scenarios**.
- Climate risk includes **physical risk**, which is the economic impact of the frequency and magnitude of natural climate-related disasters (thus affecting northern European countries with floods and southern European countries with forest fires), and **transition risk**, the negative impact of introducing climate polices to reduce CO2 emissions (mainly affecting carbon intensive industries).
- The exercise reveals that **an orderly and rapid transition minimizes costs and maximizes profits, and offsets the short-term cost of transitioning to a zero-carbon economy**, showing that companies and banks benefit from adopting green policies in order to boost a zero-emission economy.

2015

The **Paris agreement** set an ambitious goal of limiting climate change through a **global response:** *to keep the global temperature increase this century well* ***below 2ºC above pre-industrial levels*** *and to pursue efforts to limit the temperature increase further to* ***1.5ºC***.

2019

The EC proposed a **European Green Deal** calling for "**no net GHG emissions by 2050**" and a decoupling of economic growth from resource use.

2021

- In **March**, the ECB published **preliminary results of the climate stress test**, which **complements** the results of the climate stress test including **assessments of banks'** resilience to climate risks through loans, security and equity holdings.
- In **September**, the ECB published the results of the wide climate stress test.

2022

The results and methodology of the wide climate stress test will serve as the basis for the **2022 climate stress test exercise for banks** directly supervised by the ECB.

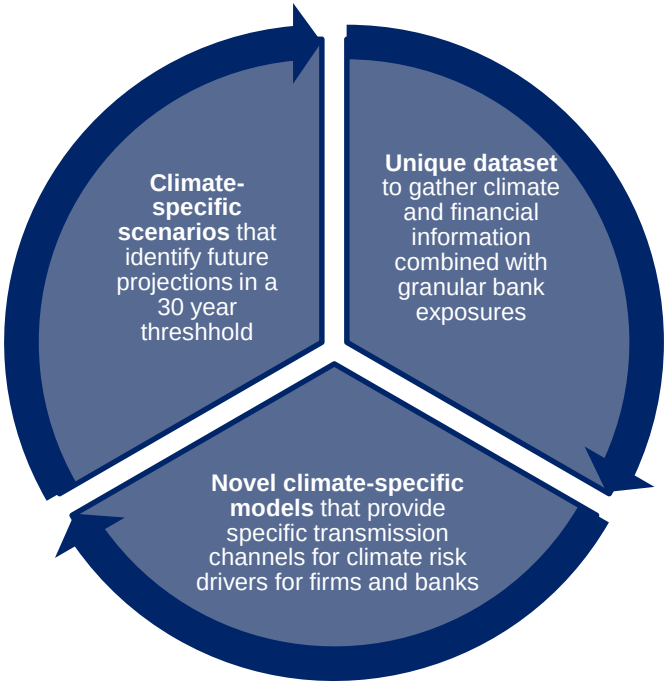
Access the full document

1 Executive summary

The objective of the ECB's economy-wide climate stress test is to assess the resilience of NFCs and euro area banks to transition and physical risk under climate policy scenarios. Within the analysis, three pillars and four distinct dimensions can be distinguished:

A **Top-down exercise** that ensures full transparency and replicability of the framework, as well as comparability in terms of the impact and final outcomes for Banks.

The exercise **assesses climate risks for four million corporates worldwide and 1,600 consolidated banking groups** across the entire euro area. This has been made possible thanks to an extended climate data collection exercise that, to the best of our knowledge, has provided the most comprehensive set of backward and forward looking climate and financial information available at central bank level.

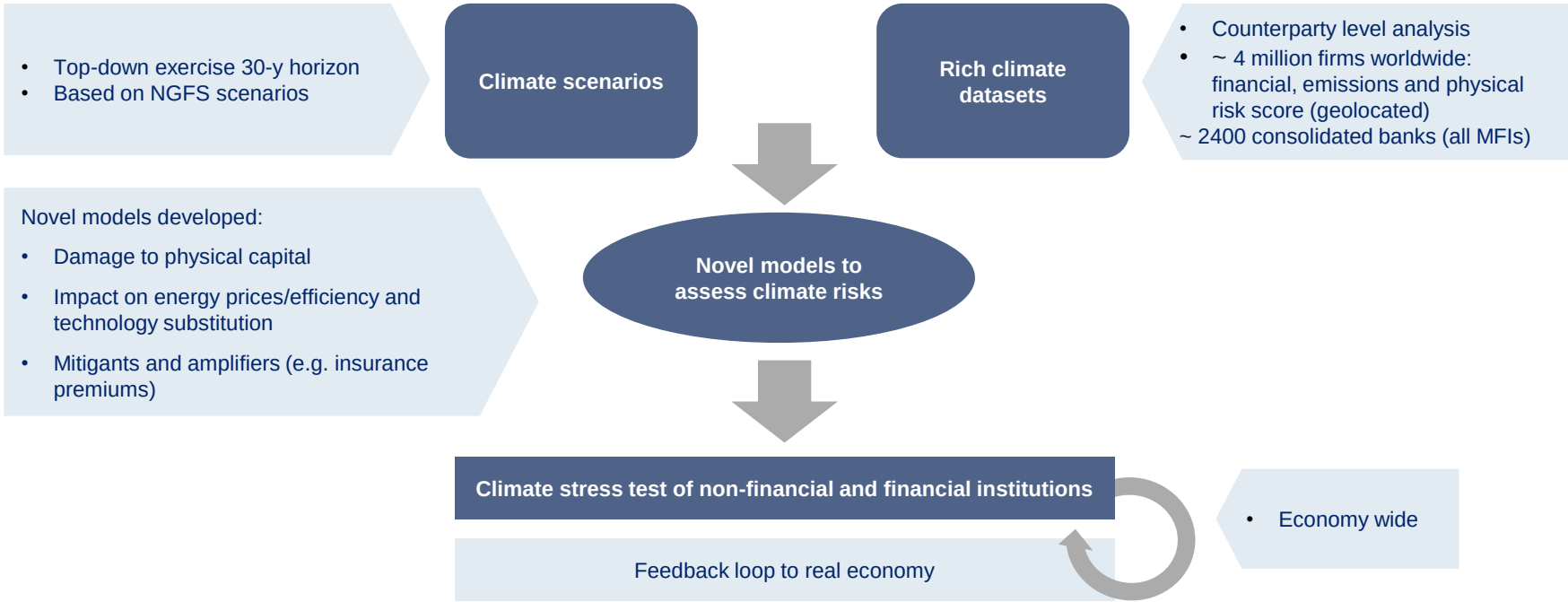


The **granularity of the exercise** makes it possible to account for the heterogeneity and uniqueness of climate risks, not only across regions and sectors but also within them.

The **interactions between transition and physical risks** have made it possible to compare the future costs and benefits of climate policy action.

2 Methodology
Key distinctive features

The ECB aims to improve the climate stress-test with the introduction of modelling and data innovations that show the interactions between transitional and physical risks at firm level over a long time horizon



2 Methodology
Differences with existing climate stress tests

The ECB's economy-wide climate stress test sits alongside a variety of initiatives by European institutions. However the ECB uses a unique analysis based on concrete climate-related scenarios

EUROPEAN CENTRAL BANK

ECB Wide Climate Stress-Test (2021)

- **Top-down** exercise.
- **Long-time horizon** (30 yr).
- **Three climate scenarios** based on the NGFS scenarios.
- **Analysis at a granular level.** Account **fully for the heterogeneous** and **unique nature** of climate risks, across and within sectors and regions.

DNB

DNB energy-transition-risk stress test (2018)

- **Top-down** exercise.
- **Short-time horizon** (5 yr).
- **Four energy transition scenarios.**
- **Analysis at a sectorial level** (e.g. bond and equity holdings, insurers and pension funds, corporate loans) **for the largest Dutch Banks.**

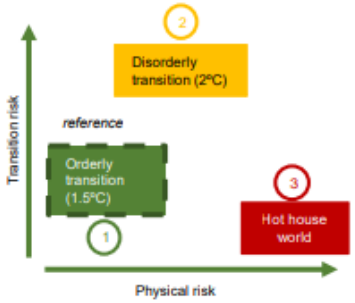
BANK OF ENGLAND

BoE Climate Biennial Exploratory Scenario (2021)

- **Bottom-up** exercise.
- **Long-time horizon** (30 yr).
- **Three climate scenarios** based on work of the NGFS.
- **Largest counterparties analyzed at a detailed level;** Remaining portfolios aggregated by geography and sector.

2 Methodology
Climate scenarios

The ECB bases its study on the NGFS scenarios: the orderly transition scenario, disorderly transition scenario and Hot House World scenario



Orderly Transition Scenario

- **Best-case** scenario
- Climate **policy** measures **well calibrated** and implemented in a **timely** and **effective** manner
- **Limited Costs** from transition and physical risks
- European **Green Deal 2050 achieved**
- **Paris Agreement** target of <2ºC **achieved**
- **Baseline scenario** for comparing different adverse scenarios

Disorderly Transition Scenario

- **Delayed implementation** of climate policy measures
- **Policy** action introduced in an **abrupt** way
- **Significant costs** from transition risks
- **Global warming mitigation** starts by **2030**
- **Physical risks greater** than in baseline scenario

Hot House World Scenario

- **Worst-case** scenario
- **No regulation** or policy aimed at limiting climate change
- **Extremely high costs** from **physical** risks
- Very limited costs from transition risks
- **Extremely high costs** related to natural catastrophes
- **Global Warming 3ºC+** by 2100
- **Paris Agreement** targets are **not met**

2 Methodology
Macroeconomic and climate projections

The selected time horizon is 30 years. Under this time horizon the ECB has made projections of three indicators (GDP, GHG emissions and Energy prices and consumption) under the three scenarios

Real GDP

- **Projected levels of Real GDP.** GDP would grow under all scenarios, the pace in which they grow however would vary among them, being the orderly transition the most beneficial and the Hot house World the worst.
- **Costs effect in GDP.** On the short-term GDP under the adverse scenario would grow the most, because transition costs are almost none. However in the medium to long term, physical risk costs would be significantly higher tan transition, causing GDP under the Orderly transition scenario to have a greater growth.

GHG emissions

- **Projected levels of GHG emissions.** Under the Hot house World scenario, these levels are above the ones in other scenarios over the entire forecast horizon.
- **CDR technologies.** The ECB assumes that Carbon Dioxide Removal (CDR) technologies would be fully available under the Orderly transition scenario and only limited under the Disorderly scenario.

Energy prices and consumption

- **Green energy production**. More efficient production under baseline scenario, causing prices to progressively go down. On the disorderly scenario, due to a delayed and abrupt adoption of green technologies, prices would be comparatively higher over most of the forecast horizon.
- **Energy consumption**. A timely and efficient use of green technologies would lower energy consumption under the baseline scenario. Under the disorderly transition scenario, consumption would fall below baseline levels due to the abrupt implementation of these technologies, that will cause prices to fall as well.

2 Methodology
Data sources and integration

The climate stress test framework is based on the combination of financial data with company data on climate and transition risks, enabling the transformation of climate effects into financial effects

The data used for the climate stress test integrates four main streams of information and combines regulatory and private sources. The data enrichment comes from combining firm-level financial information with data from euro area banks.

Financial Data

- **Financial data** (Orbis complemented by other sources, such as Eikon, Bloomberg and iBACH)

Climate information

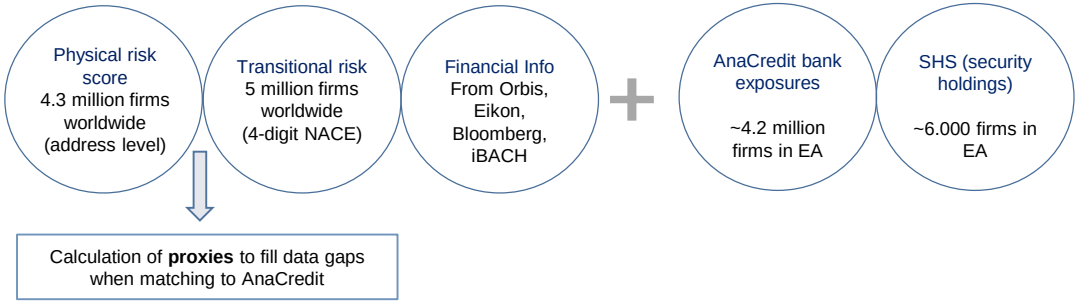
- **Climate information**, i.e., physical risk scores (Four Twenty Seven) and **company-level carbon emissions** data (Urgentem).

Individual company loans

- Subsequently, **company financial and climate information is combined** with information **on individual company loans to banks from the euro area** (AnaCredit) and corporate bond trends (SHS-G23).

Private data of physical and transition risks

- Data on **physical and transition risks** come from **private data sources** that measure companies' exposure to future natural hazards and their carbon footprint.



2 Methodology

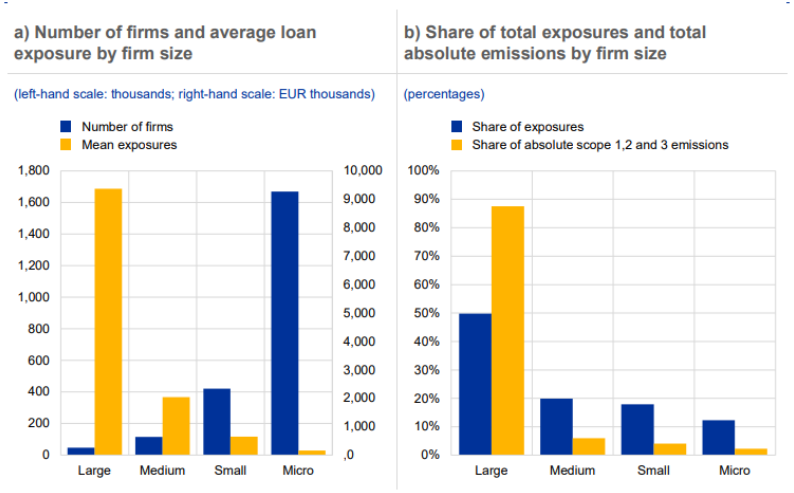
Exposure of european companies to climate risk (1/3)

The majority of firms in the sample are micro firms, although large firms represent the highest share of exposures for euro area banks. Furthermore, differences in emissions across firms of different size persist when looking at emission intensities rather than levels

Firm-level transmission of financial and climate risks

- **Large firms** represent a **very small part of the sample**, they are highly representative of euro area banks. **Large companies** are the **biggest polluters**, contributing almost 90% of total emissions.
- **Large companies produce the largest issues** and account for the largest share of lending and could therefore be considered the **largest source of transition risk for the banking sector**.

Firm-level transmission of financial and climate risks



Source: ECB calculations based on AnaCredit, Orbis and Urgentem data (2018).
Notes: Total absolute emissions refers to total absolute Scope 1, 2 and 3 emissions. Firms are categorised as large, medium, small and micro based on the size of their total assets. The thresholds for this categorisation are based on the European Commission's definition of SMEs.

2 Methodology
Exposure of european companies to climate risk (2/3)

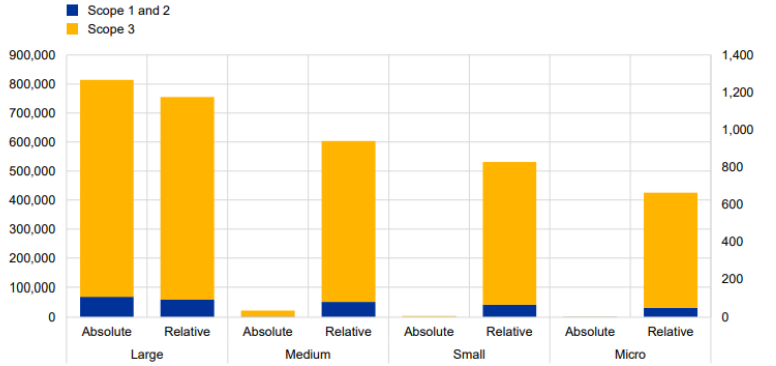
The majority of firms in the sample are micro firms, although large firms represent the highest share of exposures for euro area banks. Furthermore, differences in emissions across firms of different size persist when looking at emission intensities rather than levels

Results of emissions by sectors and regions

- The differences in average **emission intensities** are less pronounced across companies: nonetheless, micro firms are almost half as carbon intense as large firms, emitting around 600 as compared to 1,100 t/CO2e per euro in revenues.
- **Scope 3 emissions** make up by far the **highest share of emissions**, especially for large companies. This points to the need to improve reporting standards for companies around Scope 3 emissions as they are a major source of transition risk.

Emissions by firm size

Average emission intensities by firm size (right-hand side) and average emission levels by firm size (left-hand side)



Source: ECB calculations based on AnaCredit, Orbis and Urgentem data (2018).
Notes: Firms are categorised as large, medium, small and micro based on the size of their total assets. The thresholds for this categorisation are based on the European Commission's definition of SMEs.

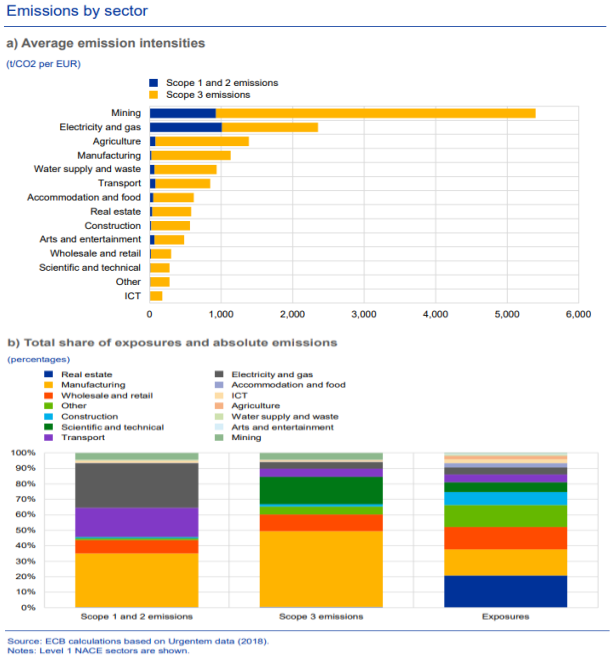
2 Methodology

Exposure of european companies to climate risk (3/3)

The majority of firms in the sample are micro firms, although large firms represent the highest share of exposures for euro area banks. Furthermore, differences in emissions across firms of different size persist when looking at emission intensities rather than levels

Distribution of emissions

- The distribution of emissions is rather **heterogeneous across sectors**: The most emission intensive sectors are **mining, followed by electricity and gas and agriculture.** On the other hand, the sectors contributing most to absolute emissions are manufacturing, electricity and gas, transport and wholesale and retail activities.
- **Bank loans are well diversified across sectors**, however, of the highest emitters, manufacturing and wholesale and retail represent more than 30% of banks' portfolios.
- **Manufacturing and wholesale** and **retail** together **receive one-third of total euro area bank loans**: this rises to 40% when banks' exposures to transport and electricity and gas are included.



3 Transmission to firms
Introduction

The NFCs have to cope with two main types of risk; transitional and physical, which will affect the probability of default and will make changes in leverage

Transition risk

The effects that transition risk has on the main components of firm profitability (i.e., revenues and operating costs) and leverage are both supply and demand driven.

- On the **supply framework**, an increase in carbon prices is assumed to reach all firms in the economy in a form of a flat carbon tax on their Scope 1 (direct) emissions. The potential introduction of a carbon tax would increase the costs for firms, especially if they operate in polluting sectors. However, in a transition scenario this cost increase may be offset by a greener, more efficient and cheaper energy mix in subsequent years as well as the adoption of carbon removal technologies.
- On the **demand side**, the effects of the transition are captured via modelling the impact of a carbon price on sales of carbon-intensive goods.

Physical risk

Physical risks directly affect firm revenues and operating expenses.

The calculation of expected losses from physical risk combines **direct impact** on firms' exposure to extreme weather events with **indirect impact**, such as the expected damage at the regional level as a share of GDP. The modelling framework incorporates these direct and indirect effects to compute the expected losses to firms' physical capital, which leads to key findings. Damage across all hazard types would be higher in a disorderly transition as compared with an orderly transition scenario, while the hot house world scenario would give the highest results.

Damage to physical capital is reported as a share of total assets and is shown to be higher under a hot house world scenario for all types of natural disasters.

However, it is worth noting that these effects are significantly amplified by outlier firms in the sample, especially in the long run, if climate mitigating policies are not introduced. That means that, even if these extreme events are expected to affect a relatively low number of firms, the transmission channel to the rest of the economy (through financial exposures) might greatly amplify the aggregate impact on the system.

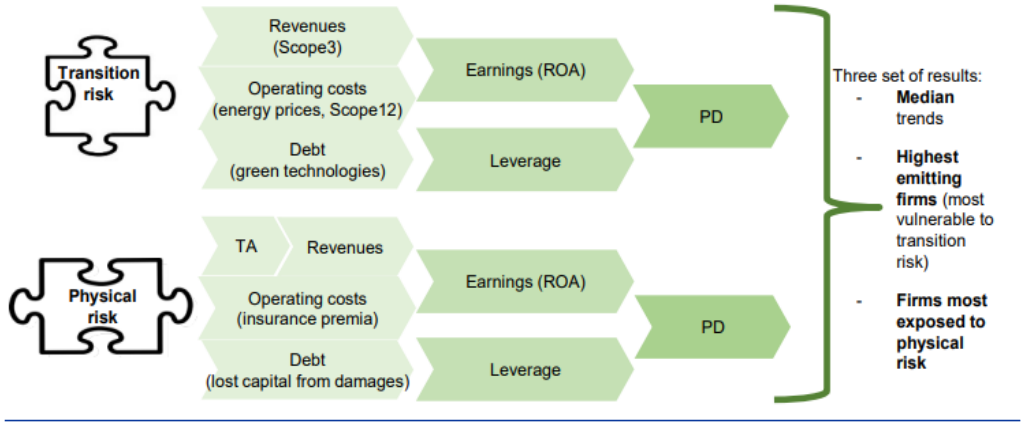
3 Transmission to firms
Introduction

The NFCs have to cope with two main types of risk; transitional and physical, which will affect the possibility of default and will make changes in leverage

Transition and physical risk

- As the probability of default of individual firms can be affected by **transition** and **physiscal risk**, there are findings that are discussed for different subsamples of the dataset: the median European firm, the highest emitting firms (i.e., those firms that are relatively more affected by transition risk), and the firms that are most exposed to physical risk.
- The following chart displays the cascade for the estimated and projected equations that are derived for NFCs.

Schematic overview of climate risk transmission to firms through credit risk



Source: ECB.
Note: Although the effects of transition and physical risk on firms' fundamentals are represented separately here for clarity, all the equations are estimated jointly.

3 Transmission to firms

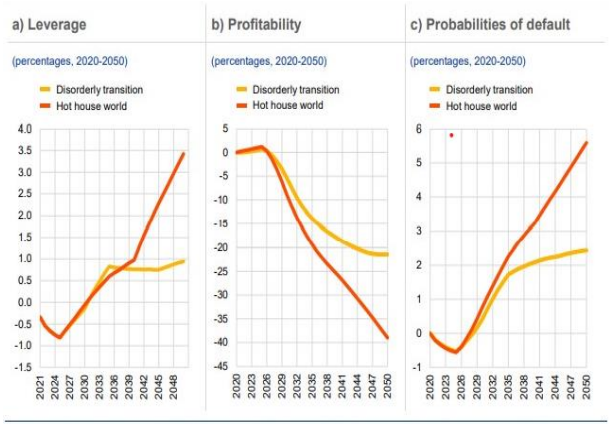
Impact on a median European Firm

Overall, the median European firm is less indebted, more profitable and has a lower probability of default (PD) at the end of the horizon under the orderly transition scenario as compared with the two adverse scenarios

- **Leverage**: The increase in costs, therefore a higher leverage, is primarily driven by implementation of the investment projects in green technologies and by the debt that is incurred to cover physical damage. In 2050, leverage becomes approximately 3.5% lower with orderly transition as compared with the hot house world scenario, thus signaling that the long-term impact from physical risk on firms' leverage is expected to be more substantial than the impact from transition risk.

- **Profitability**: It is only in the first few years that the profitability of the median firm is slightly higher in the hot house world than under the orderly transition scenario, but the effect is reversed shortly thereafter and by 2050 profitability is expected to drop by 40% compared with orderly transition if no policy action is taken. This dynamic is visible also when looking at the disorderly transition scenario.

- **Probabilities of default**: The median firm would have a slightly higher PD (~0.5%) with orderly transition during the policy implementation as compared with the hot house world, but this effect would be quickly reversed, leading to PDs becoming approximately 5.5% higher by 2050.



Source: ECB calculations based on NGFS scenarios (2020b), Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).
Note: All charts display median percentage changes under the disorderly transition and hot house world scenarios relative to baseline (orderly transition).

(1) Detailed results in annex

3 Transmission to firms

Impact on the highest emitting firms

The sectoral breakdown of high-emitting firms as compared with the entirety of the sample reveals a higher concentration of transition risk in specific sectors. Transition risk is heavily concentrated in agriculture, mining, manufacturing and electricity and gas.

The impact of climate risks on the **highest emitting firms** is greater than for median firms and is reflected in higher leverage and more pronounced differences across scenarios.

- The **leverage dynamic is more prominent than for median firms** and reflects the need for high-emitting companies to raise more capital to replace their technologies and reduce emissions.
- **By 2040 leverage in the hot house world would be higher than under the other two scenarios**, with the trend increasing, thus highlighting once again the relevance of physical risk in the long run as compared with transition costs.

High-emitting firms differ from the rest of the sample in the need to raise substantially more debt during the transition phase to replace technologies with eco-friendly options.

- The **profitability of high-emitting firms is also significantly impacted in the short run** in the case of transition; the latter would, however, have strong long-term benefits.
- The **increase in PDs with orderly transition** at the beginning of the period is **higher for high-emitting** than for median firms, although it is still offset by the long-term benefits of climate mitigating actions.

Coal mining is the highest emitting sector. Leverage and PD is extreme. This would likely lead either to the default or to their complete reconversion to different sectors.

- The transition of coal-mining firms to a greener economy would require them to triple their debt and raise their leverage from 27% to 70% or 90% under the orderly and disorderly transition scenarios, respectively.
- Coal mining firms are shown to be faced with great survival or reconversion challenges in the case of a transition scenario, however the current framework should be refined to capture sector-specific dynamics.

3 Transmission to firms

Impact on firms highly exposed to physical risk

The firms that are most vulnerable to physical risk would benefit strongly from a timely and orderly transition given that the consequences of more frequent and severe natural disasters if no policy action was taken would significantly affect their financial performance.

Effects on leverage will depend on actions taken to address climate challenges

- **Firms highly exposed to physical risk** would suffer from a strong increase in leverage over the medium-to-long run due to higher costs, caused by the increased damages from natural catastrophes should climate change not be mitigated.
- By 2050, **leverage is projected to be 22.5% higher** in the **hot house world** as compared to orderly transition.

Profitability will have a major change depending on the changes made

- **High-physical-risk** firms would also experience the **largest drop in profitability** as compared with other firm samples if no policy action is taken.
- The profitability dynamics are mainly driven by significant increases in operating costs (higher insurance price) and natural disasters would make disruptions in the production chain, leading to a decline in revenues.

Firms that would have serious financial stability concerns in a hot house world

- The **probability of default** of high-physical risk firms is projected to increase by **2050 by almost 25%** under the hot house world scenario, a figure that is five times larger than what is observed for median and high-emitting firms.
- The increase in projected probability of default over the forecast horizon under the disorderly transition scenario is also significantly higher than that observed for median and high-emitting firms under the same assumption.

It is relevant to take into account the importance of creating a policy

- Given the irreversibility of climate change, should policies to mitigate it not be introduced, the **long-term consequences of physical risk are expected to keep increasing** over time even beyond the time horizon considered in this study.

4 Transmission to banks
Credit risk channel (1/3)

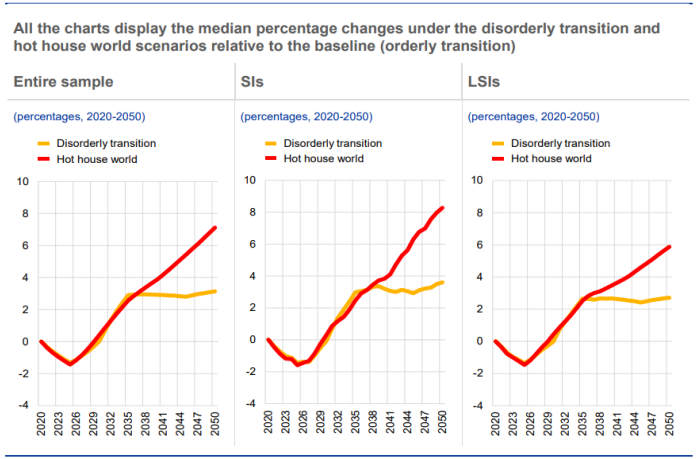
The ECB climate stress test evaluates the impact of climate risk on the euro area banking system through the credit and market risk channels. Different climate scenarios are used in order to quantify the impact on banks' credit risk, the changes in the PDs and LGDs of banks' loan books

The analysis combines the projections on PDs and LGDs to estimate the expected losses on banks' corporate credit portfolios at the end of the time horizon (2050).

PD

- In the **short-run** banks would suffer from the costs of a green transition; however, this effect is reversed in the **medium to long run**, thus pointing to the economic benefit of an orderly transition. The PD in the hot house world scenario would increase to a 7% by 2050 relative to the baseline. While in a Disorderly transition stabilises at around 3% (as compared with the baseline) by 2050.
- **Significant banks** are more severely affected under a scenario without transition, resulting in a 2% higher increase in their median PDs under the hot house world scenario by 2050 relative to other Banks.
- Bank-level results indicate that in 2050 nearly all banks would **benefit from an orderly transition** as compared with the hot house world scenario.

Probabilities of default: percentage changes relative to the baseline scenario



Source: ECB calculations based on NGFS scenarios (2020), AnaCredit, Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).
Notes: Banks are classified as significant institutions (SI) based on the definition set out in the SSM Regulation and SSM Framework Regulation. Median bank refers to the median probability of default per year and scenario of the respective sample.

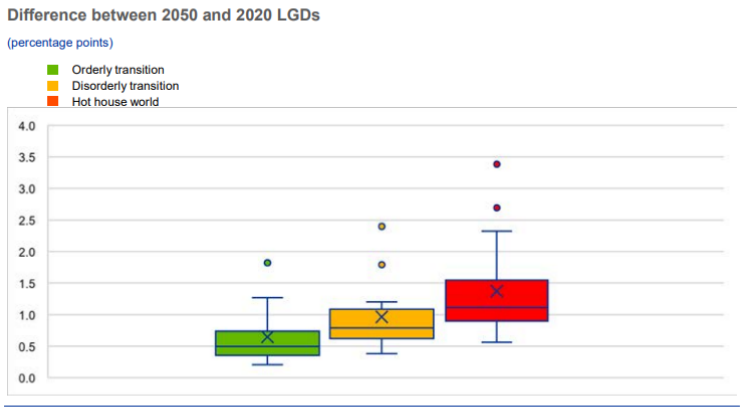
4 Transmission to banks
Credit risk channel (2/3)

The ECB climate stress test evaluates the impact of climate risk on the euro area banking system through the credit and market risk channels

Loss given default

- The **share of loans** protected by collateral is extremely heterogeneous across countries, although it is approximately **50%** on average, of which most is represented by physical collateral.
- Countries with the **largest amount of collateral** in absolute terms correspond to those that also have the largest exposures, namely Germany, Italy, Spain and France.
- The impact on **corporate-credit-portfolio lost given default** is mainly driven by damage to physical collateral over the 30-year time horizon. Due to the impact of the damage to physical collateral, banks would experience the greatest average increase of their portfolio lost given default in a hot house world.
- A hot house world would cause bank portfolio **lost given default** to be more dispersed, thereby affecting bank portfolios in some countries disproportionally worse than in others, highlighting the non-linear nature of physical risk.

Distribution of the increase in portfolio LGDs due to physical damage and transition shocks



Source: ECB calculations based on NGFS scenarios (2020), AnaCredit, Orbis, Urgentem and Four Twenty Seven data (2018).
Notes: Portfolio LGDs are the average of loan-level LGDs weighted by their exposure amount.

4 Transmission to banks
Credit risk channel (3/3)

The ECB climate stress test evaluates the impact of climate risk on the euro area banking system through the credit and market risk channels

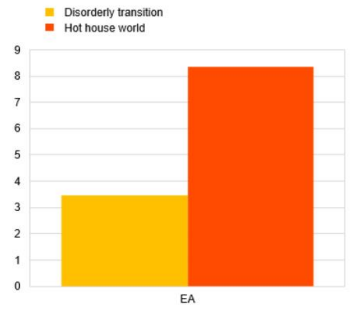
Expected losses

- The expected losses of bank credit portfolios are minimal in the event of an orderly transition towards a greener economy. **Euro area banks would face higher expected losses of around 8%** in a hot house world relative to an orderly transition.
- The impact on expected losses from climate change is mainly driven by **physical risk** which diverges the most between scenarios.
- Banks domiciled in some countries would experience a much more pronounced **increase in expected losses** under the hot-house-world scenario relative to the baseline as compared to the Euro area average.

Distribution of expected losses by 2050

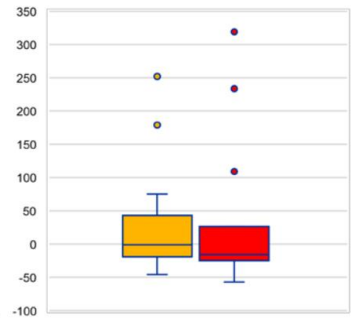
a) Total Euro area percentage changes under the disorderly transition and hot house world scenarios relative to the baseline (orderly transition)

(percentages)



b) Distribution of country-level deviations from the Euro area average

(percentages)



Source: ECB calculations based on NGFS scenarios (2020), AnaCredit, Orbis, Urgentem and Four Twenty Seven data (2018).
Notes: Total refers to the total change in bank-level expected losses between the respective scenario and the baseline between 2020 and 2050 and across euro area banks.

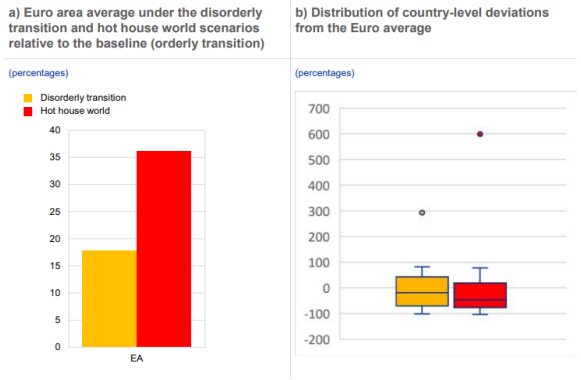
4 Transmission to banks
Market risk channel

The ECB climate stress test evaluates the impact of climate risk on the euro area banking system through the credit and market risk channels. Internal ECB pricing tool is used to capture linear and non-linear changes in the prices of debt instruments in the event of market risk shocks

The impact of market risk is somewhat limited as compared with the credit-risk channel, however it follows similar dynamics in terms of scenario comparison and country differences.

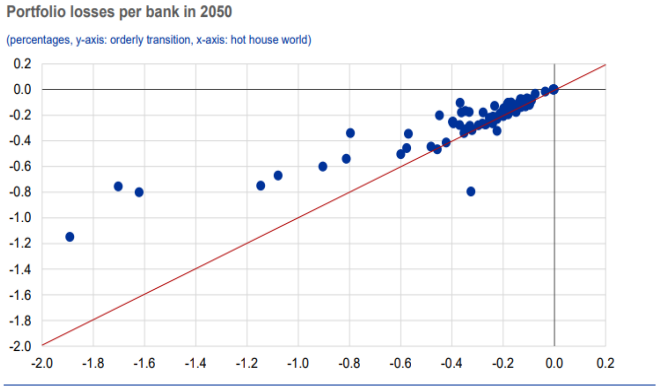
- **Losses in the fair value** of the corporate bond portfolio are almost always higher in the hot house world scenario than with an orderly transition.
- The increase in market losses in a **hot house world is more severe than in a scenario with orderly transition**, relative to the baseline. At the same time, market losses seem to be homogeneous across banks.

Distribution of market losses between 2020 and 2050 relative to the baseline



Sources: ECB calculations based on Iboxx, SHS-G data (2018).
Notes: Average refers to the average change in bank-level expected losses between the respective scenario and the baseline between 2020 and 2050, and across euro area banks.

Market losses for banks' corporate bond portfolio



Sources: ECB calculations based on Iboxx, SHS-G data (2018).

5 Conclusions and next steps

The ECB results show that firms and banks clearly benefit from adopting green policies early on to foster the transition to a zero-carbon economy. The exercise also reveals that the impact of climate risk is concentrated in certain regions and sectors of the euro area

Short term transition costs	**Short term transition costs** are smaller than costs related to uncontrolled climate change in the long run. An **early adoption** of climate transition policies would bring benefits in investing in and rolling out more efficient technologies, to ensure that targets of the Paris agreement are met.
The effects of climate risks	If climate change is not mitigated, effects of climate risks would moderately increase until 2050, **concentrating in particular sectors and geographic areas** (e.g. Mining, electricity and gas sectors). Firms located in geographical areas that are most exposed to physical risk would face a considerable decline in their creditworthiness as a consequence of more severe and frequent natural disasters if climate change is not mitigated.
Policies to green transition	If **policies to green transition** are not introduced, physical risks increase over time in a non-linear fashion and due to the irreversible nature of climate change. For that reason, an orderly transition should be conducted to mitigate transition costs and future physical costs.
Climate physical risks and expected losses	**Climate physical risks** would affect in a significant way those banks and companies that own portfolios concentrated in certain areas that are exposed to more frequent natural disasters resulting from climate change in a Hot house world scenario. **Banks expected losses** would increase driven by physical risk, specially those of European banks whose loans are concentrated in countries with low levels of collateral protection or high exposure to physical risks. These would happen if climate risks are not mitigated under an orderly transition scenario.
Next steps	The climate stress-test will be used as a basis for developing appropriate climate scenarios and support the supervisory bottom-up analysis. The stress test would be used to feed the climate stress test of the Eurosystem balance sheet (1Q2022).