MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

Climate change risks and their implementation in the ECB's monetary policy framework

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Abstract

This thesis examines the potential impacts of climate change on the wide-economy and financial system, with particular focus on the current and future expected changes in the ECB's monetary policy framework resulting from the incorporation of climate-related considerations.

A changing climate affects the environment while introducing systemic risks in the economic system. Altered weather patterns, raising temperatures and more frequent extreme weather events jeopardize crop yields and infrastructure, increasing uncertainty and potentially resulting in upward price pressures.

At the same time, new policies and regulations introduced by governments worldwide to decarbonize the economies and try to limit the physical damages of climate change introduce transition risks, especially for those economic sectors that are most reliant on fossil fuels, such as mining, agriculture, electricity and gas.

The transition to a carbon-neutral economy creates opportunities and growth in some sectors, such as renewable energies, while jeopardizing the profitability and even survival of carbon-intensive activities, forcing capital write-offs and leaving such sectors with an increasing amount of stranded assets, weaker balance sheets and lowered borrowing potential.

Such impacts, associated both to the physical damages of a changing climate and to the transition towards a carbon-neutral economy, extend from households and non-financial corporations to the financial sector. Insurance corporations are faced with increased liabilities related to extreme weather events damages, while banks are likely to see deteriorations in the default probabilities of their portfolios. The extent of such damages depends on the timeliness and gradualness of the green transition: an immediate and orderly green transition is expected to limit physical damages and the deterioration in corporates' default probabilities when compared to other possible future scenarios, such as a delayed transition or no transition at all.

The ECB, in its role of monetary authority and banking supervisor, is called to monitor and ensure price stability and the soundness of the European banking sector. This is done through scenario analysis and climate stress testing, assessing the potential developments of macroeconomic variables and banks' balance sheets under different, but plausible, climate scenarios.

Moreover, since the ECB is mandated to support EU's general economic policies (without prejudice to the primary mandate of price stability), changes to its collateral framework and new eligibility criteria for the assets purchase programs have been developed, setting the path for a gradual decarbonization of the Eurosystem's balance sheet.

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1. Introduction to climate change and its effects on macroeconomic variables

1.1 Climate change

Climate change is one of the main challenges of our time. It gathered significant attention in recent decades due to its far-reaching implications for society, the environment and the world economy.

Current scientific consensus points towards human activities, particularly those related to fossil fuels, as a leading cause of the increase in greenhouse gas concentrations in the atmosphere, leading to a warming trend in the Earth's climate, with all the due implications.

Rising temperatures are rooted in the greenhouse effect, where certain gasses such as methane (CH4), carbon dioxide (CO2), nitrous oxide (N2O) and ozone (O3) trap heat within the atmosphere, disrupting the balance of the climate system.

It is estimated that, since the beginning of the industrial revolution, human activities have increased the atmospheric concentration of methane by over 150% and carbon dioxide by over 50%, with these two gasses being responsible for most of the greenhouse effect and an average global surface temperature rise of about 1.2 °C. [1]

Most of the anthropogenic CO2 emissions come from the combustion of fossil fuels (oil, coal and natural gas), with additional contributions from the production of fertilizers and cement. Anthropogenic methane emissions instead are mainly related to agriculture, fossil fuel production and waste.

The increased emissions of greenhouse gasses from human activities and their subsequent accumulation in the atmosphere intensify the greenhouse effect, exacerbating the rate of warming and the associated side effects.

Climate change is causing shifts in weather patterns, resulting in more frequent and intense extreme weather events, such as hurricanes, floods, droughts and heatwaves.

The impact of climate change is not limited to the environment alone, as it also influences socio-economic systems: changes in temperatures and precipitation patterns affect agricultural productivity and water availability, with direct effects on food and energy productions and costs. Additionally, natural disasters often result in physical damages to infrastructure, private property and production facilities, creating supply chain issues and added costs.

For these reasons, in 2015, 195 countries signed the Paris Agreement, which represents a global effort to fight climate change. Under this agreement, participating nations pledged to work collectively to limit global warming to well below 2 degrees Celsius above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 degrees Celsius.
The Paris Agreement can be considered as based on a bottom-up approach, as it encourages countries to set their own emission reduction targets (known as Nationally Determined Contributions, NDCs) recognizing the different circumstances and capabilities of nations, while promoting shared responsibility about climate change. [2]

As the Earth's climate is undergoing more or less significant shifts, understanding the impact of this changes on human activity, and trying to limit them, has become increasingly critical to ensure a smooth continuation of economic activity.

To this end, the Intergovernmental Panel on Climate Change (IPCC), created back in 1988 by the World Meteorological Organization and the United Nations Environment Program, provides governments with scientific information that they can use to develop climate policies. The IPCC comprises thousands of scientists worldwide that assess and synthetize the latest scientific papers on climate change, to provide a comprehensive summary of what is known about its drivers, impacts and future risks, and how adaptation and mitigation can reduce those risks. [3]

1.2 Macroeconomic impacts of climate change

Climate change poses both direct and indirect risks to economic growth. Direct impacts include the physical damages from extreme weather events that lead to disruptions in production, infrastructure and supply chains. Indirect impacts arise instead from the transition to a low-carbon economy, and they include the effects on policy changes, technological advancements and subsequent market transformations. These transition risks are likely to affect industries differently, leading to the reallocation of resources across different sectors and potential productivity losses.

It is thus clear that, beyond the environmental ramifications, climate change introduces substantial risks to the global economy and has direct and visible implications on the main macroeconomic variables.

An economy's health can be judged though the analysis of different macroeconomic variables, such as gross domestic product (GDP), unemployment rate, inflation rate, interest rates and

exchange rates (of a country's currency with respect to other currencies), just to mention the main ones.

Climate change can generate both negative and positive influences on GDP. On the negative side, physical damages from extreme weather events may affect infrastructure and production activities, leading to lower or even negative GDP growth. Changes in weather patterns and rising temperatures do also have direct effects on agriculture, potentially lowering crop yields and reducing agricultural output. However, there are other economic sectors, mainly related renewable energy production and storage, that are likely to experience growth opportunities thanks to the transition towards a low-carbon economy.

Inflation is another macroeconomic variable that can be heavily affected by climate change. As extreme weather events create physical damages disrupting supply chains and damaging crops, commodity prices (especially energy and food) can experience significant volatility. This may lead to higher production costs and consumer prices, undermining the real purchasing power of individuals and households. Other inflationary pressures linked to the physical risks of climate change can come from increased insurance premia to cover for the more frequent weather externalities.

The transition to a low-carbon economy is also likely to involve changes in energy prices and in the price of carbon-intensive goods, due to the introduction and subsequent increase of carbon taxes, aimed at monetizing the negative externalities of polluting economic activities and products, while incentivizing the shift towards greener alternatives.

Moreover, as will be explained in better detail later on, the late and abrupt governments' introduction of mitigation policies (referred to as disorderly transition) can exert additional inflationary pressures on economies, as resources are allocated en masse towards certain sustainability projects.

Even unemployment is not immune to the direct and indirect effects of climate change. Industries particularly susceptible to the impacts of extreme weather events (such as agriculture, but even tourism) or heavily reliant on fossil fuels (such as mining) are the ones that will be most affected by climate change and the transition to a greener economy and will likely suffer significant job losses and/or income disparities. Moreover, the damages or destruction of economic activities caused by extreme weather events can also add to unemployment in the affected geographical regions.

Conversely, new job opportunities are likely to materialize in the renewable energy sector and for the development of energy-efficient technologies, as well as in all those activities aimed at climate change mitigation and adaptation.

It is thus increasingly clear that changes in the current production, consumption and living habits are required to limit the impacts of climate change, and these changes may themselves disrupt the economic and financial system. Policy makers are expected to implement mitigation strategies aimed at minimizing the effects of climate change on the economy. In this regard, investments in infrastructure resilience and climate-proofing can help mitigate the physical damages associated with extreme weather events, while supporting long-term growth.

2. Climate change as a risk driver in asset prices

As already said, climate change has real impacts on the economic system, resulting in (indirect) effects also on financial markets. Climate change can represent a source of short and long-term risk for investors via physical and transitional risks, threatening the overall stability of the financial system through different channels.

A first transmission channel is through investors sentiment and market perception, as investors may shift their preferences towards greener investment products, affecting capital flows, asset prices and market dynamics. This can be amplified by regulatory changes and/or regulatory uncertainty, as the possibility of stricter emission standards or carbon pricing mechanisms adds uncertainty on firms' profitability (especially for the high-emitting ones), increasing perceived risk and shifting the market sentiment towards other alternatives.

Secondly, climate-related risks affect credit and counterparty risks. As corporations become more exposed to climate-related externalities, investors face higher credit risk on their bond and loan exposures, and higher counterparty risks associated with equity investments.

Additionally, regulatory changes and technology advancements, such as carbon pricing, stricter emission targets, renewable energy targets and developments in renewables efficiency and storage capacity can lead to stranded fossil fuel assets. Stranded assets become obsolete or uneconomical before the end of their expected economic life, due to technological advancements, changes in regulation or market conditions, leading to negative balance sheet effects for their owners.

In the context of climate change, we distinguish two main categories of stranded assets, both associated with the fossil fuel industry:

- Infrastructure stranded assets: physical assets such as pipelines, power plants and refineries that may lose their value as the demand for and the profitability of fossil fuels decline. As renewable energy technologies become more competitive, existing fossil fuel infrastructure can become underutilized or obsolete, resulting in stranded assets that fall short of their expected returns on investment.
- Reserves stranded assets: fossil fuel reserves may become unusable if policies are advanced to restrict the consumption (and extraction) of fossil fuels, preventing oil and gas corporations to fully exploit such known resources.

Nevertheless, climate-related risks do not appear to be fully reflected in asset prices so far. Financial markets seem to suffer from informational inefficiencies that amplify climate-related capital misallocations. There are several reasons why assessing and pricing climate-related risks can be challenging for financial market participants.

First of all, the absence of a carbon pricing mechanism able to capture climate-related externalities together with incomplete, inconsistent and insufficient disclosures from firms, leaves financial markets unable to fully account for climate risks. In fact, disclosures remain patchy among firms, and they are incomplete as they generally fail to acknowledge Scope 3 emissions, meaning those generated by the product's usage during its lifetime. Moreover, as climate risks are likely to materialize over a long-term time horizon, the absence of cost incentives to address this externality, such as an increase in carbon taxes, makes it unlikely that firms' returns will be affected in the short run.

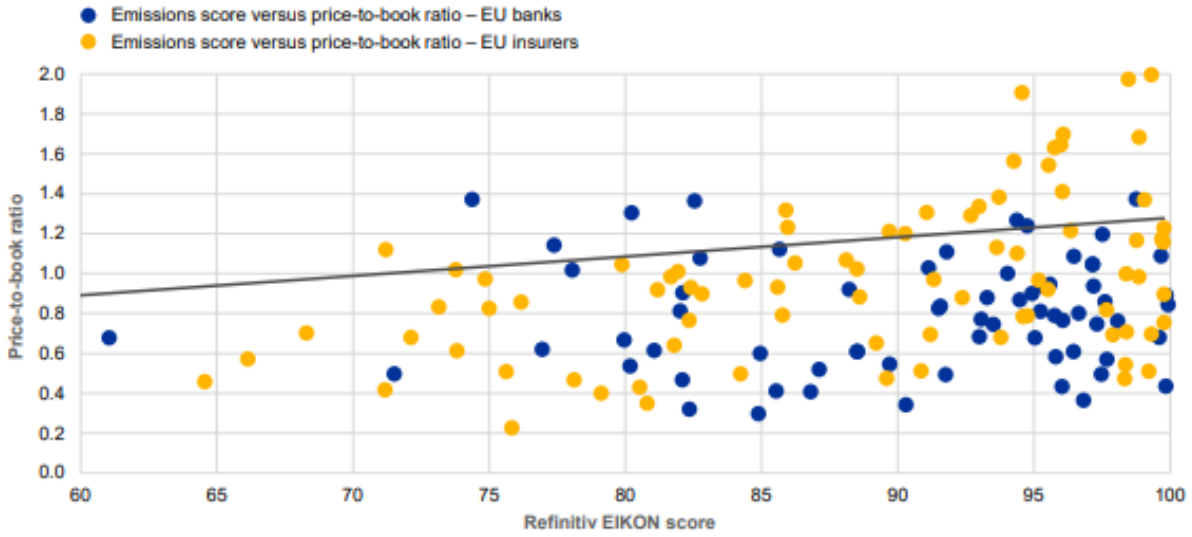
Informational inefficiencies, such as the non-convergence of environmental scores for products across the main index providers, can also explain the limited pricing differentials in green assets compared with other assets. The lack of standardized metrics for quantifying and comparing climate risks makes it difficult to assess and compare their impacts across sectors and individual corporations.

For these reasons, greener firms seem not to be outperforming other sectors.

Still, some differences can be found in the insurance sector. Empirical evidence shows that environmental disclosures have limited correlation with stock market valuations for banks, while they have some for insurers.

Figure 1 shows how the relationship between an environmental score and the price-to-book ratios for a sample of large euro area insures is somewhat positive and statistically significant, likely reflecting greater investors scrutiny of insurers owing to their higher perceived exposure to physical climate risks as a result of their insurance liabilities.

Figure 1 – Environmental score and price-to-book ratios of a sample of large European banks and insurers



Sources: Bloomberg, Refinitiv EIKON, S&P Global Market Intelligence and Dealogic

In general, the limited evidence that financial institutions are actively reducing the carbon intensity of their portfolios supports the idea that market discipline is still not effective in curbing transition risk. Reporting on greenhouse gas (GHG) emissions currently remains patchy among companies, especially large fossil fuel companies which are responsible for a significant share of global carbon equivalent emissions. In this regard, raising awareness about the potential impacts of climate-related risks should remain an important task for supervisory authorities, and focus should be placed on strengthening climate and environmental disclosures. [4]

3. Rationale for central banks to include climate considerations in their policy frameworks

3.1 Central banks' role of maintaining price stability

Central banks can help ensure that the financial system is resilient to the transition to a low-carbon economy, by providing more and better information to market participants on the risks stemming from climate change.

Central banks and supervisors taking climate-related and environmental considerations into account may be seen as controversial, but it is not. In fact, the economy will likely be subject to increased shocks from climate and environmental crises, while undergoing one of the biggest structural transformations in modern history that will inevitably affect also the financial sector.

The primary objective of central banks is price stability, which is to preserve the value of their currencies, by achieving low and stable levels of inflation. Central banks can pursue price stability only if they can understand, assess and forecast how economic shocks and trends affect inflation and the effectiveness of monetary policy measures.

Under this view, accounting for climate and environmental risks is no different than considering factors such as globalization, demographics and financial innovation. Central banks must adapt their data and economic models to be able to assess the monetary policy implications of climate change and environmental degradation, as well as the ones coming from transition policies. They must also consider their exposures to climate-related risks when designing monetary policy instruments and assessing the composition of their balance sheets. [5]

Considering the ECB, in its roles of monetary policy authority and banking supervisor, it is called to address the financial and economic risks associated with climate change and the green transition of European countries.

Several reasons can be identified that clearly explain why the ECB must include climate change considerations in its monetary policy framework:

- Climate change poses systemic risks to the financial system and the economy as a whole. Incorporating C&E (climate and environmental) considerations is the only way to enhance the ECB's ability to identify and address these risks, with the aim of safeguarding financial stability and long-term economic resilience.

- Price stability: climate change and the green transition can have strong implications on price stability. Extreme weather events, supply chain disruptions and transition risks have the potential to impact inflation dynamics.
- Financial sector resilience: both climate change and the green transition can lead to financial instability. Ensuring that the financial sector can withstand and adapt to these challenges is the ECB's task, in its role of banking supervisor.
- Sustainable development: even though the main mandate of the ECB is price stability, it also has to support the Union general economic policies. Supporting the transition to a low-carbon economy, the ECB promotes sustainable growth, contributing to the long-term development and well-being of the European society. [6]

It is also worth noticing that the Eurosystem central banks, that is, the ECB and the National Central Banks (NCBs) of the countries that have adopted the Euro as a currency, have already defined a common stance for applying sustainable and responsible investment principles in the euro-denominated non-monetary policy portfolios that they each manage under their own responsibility. These portfolios contain the assets held by the Eurosystem central banks that are not related to monetary policy operations, such as staff pension funds. This is going to help the Eurosystem members to contribute to the transition to a low-carbon economy and to EU climate goals. The common stance also prepares the ground for the measurement of greenhouse gas emissions and other sustainable investment-related metrics of these portfolios.

This is particularly important when considering that central banks use their balance sheet in the pursuit of their mandate: the preservation of price stability sometimes require central banks to take risks onto their balance sheets. [6]

One example is the one of quantitative easing (QE), where central banks absorb duration risk by purchasing long-term bonds from the private sector. Such a policy is not motivated by a profit potential, but by the realization of the need to provide a policy stance that is more accommodative than what could be achieved by the simple reduction of policy rates.

It thus becomes of paramount importance to preserve the soundness of central banks' balance sheets. Available evidence suggests that, for the pursuit of price stability, it is better for central banks to keep balance sheets that are aligned with the Paris Agreement. Failing to do so would likely add macroeconomic volatility, which in turn would complicate the conduct of monetary policy.

In fact, central banks taking climate and environmental risks into account supports price stability in two ways. On one side it contributes to preserve the soundness of their balance sheets, allowing the orderly conduct of the needed monetary policy operations, and the preservation of the market trust towards the institution. On the other side, it withdraws support from emission-intensive activities that could fuel macroeconomic volatility in the medium to long term.

This is especially important for the ECB which, in addition to price stability, has the secondary objective of supporting the general economic policies of the European Union. This means that, when choosing between two instruments, or calibrations of instruments, that are equally conducive to price stability, they will choose the one that is most supportive of EU's general economic policies and objectives, one of which is climate neutrality.

3.2 The implications of the European Climate Law for the ECB

To this end, the European Union adopted the Climate Law to fulfill its commitment to the Paris Agreement. This package is made of three main elements. First, a reduction of the EU greenhouse gas emissions by at least 55% by 2030 compared to 1990 level, with the objective of achieving climate neutrality by 2050 and aim for negative emissions thereafter. Second, a framework for assessing progress and checking whether national and Union measures are consistent for the goal. Third, the introduction of a European Scientific Advisory Board on Climate Change, to ensure that the most effective instruments are used, and policies are based on up-to-date scientific insights.

Even though the Climate Law doesn't directly bound the ECB, it undoubtedly affects its monetary policy and supervision tasks, as the bank will have to consider the Law's climate-neutrality objectives when implementing its policy stance. [7]

To make an example, in October 2022, the ECB started tilting the reinvestments of corporate bonds (held under the Corporate Sector Purchase Program, CSPP) towards issuers with a better climate performance, instilling a decarbonization path for their corporate asset holdings that is compatible with the Paris Agreement.

The Eurosystem's tilting framework relies on a climate scoring tool to assess the issuers' climate performance based on three dimensions:

- A backward-looking carbon emission intensity sub-score, reflecting past greenhouse gas emissions.
- A disclosure sub-score, which accounts for the quality of the provided emissions disclosures.
- A forward-looking sub-score, evaluating the expected future changes in the issuer's emissions.

These sub-scores are then aggregated into an overall issuer's climate score that provides a basis for the rate of benchmark and limit adjustment, affecting future purchases and reinvestments, thus the issuer's weight in the portfolio.

Tilting implies that the share of assets on the Eurosystem's balance sheet issued by companies with a better climate performance will have purchase limits above those corresponding to neutral benchmark weights, at the expense of stricter purchase limits for issuers with poorer climate scores. Moreover, stricter maturity limits are imposed on issuers with poor climate performance. [7]

Two reasons can be identified behind this decision. First, the ECB considered it essential in order to effectively pursue it primary objective of maintaining price stability, as carbon-intensive issuers are more vulnerable to climate risks, and they thus introduce more risk in the Eurosystem's balance sheet, with detrimental effects on its soundness. Second, "tilting" the CSPP also serves the ECB's secondary objective of supporting the general economic policies of the European Union. [6]

A similar reasoning will be applied to the public sector holdings, which account for the majority of the monetary policy assets of the ECB, when a clear and shared framework will be developed to determine their climate and environmental intensity risk (the issuer's progress towards the Paris Agreement objectives). In fact, the current issue with public sector holdings, that represent more than 50% of the ECB's portfolio, is that the climate and environmental intensity risk of these assets is still not easily understandable in absence of a clear framework. [6]

4. The role of (climate) stress testing and ECB's economy-wide climate stress test

4.1 Supervisory stress testing

One important tool that central banks have and can use to assess and monitor the soundness of the financial sector in different (climate) scenarios are stress tests.

Stress tests became a common tool during the financial crisis, when they were primarily used to identify capital shortfalls in the banking sector and to enhance market discipline, by publishing data on a bank-by-bank basis, with banks judged to have either "passed" or "failed" the test.

Since the crisis, the applications of stress tests have evolved, making them become a key part of the supervisory and financial stability toolkit for assessing risk profiles and performance under different (and adverse) macroeconomic conditions. In Europe, stress tests are now used as a starting point for discussion between banks and supervisors as well as for macroprudential policymakers.

It has become common opinion that stress tests promote transparency, improve market discipline, foster banks' own risk management capacity and inform prudential decisions of both a micro and macro nature.

Two main categories of stress tests are conducted by the ECB and EBA (European Banking Authority), following a bottom-up or top-down approach.

In bottom-up exercises, regulators develop a macro-financial scenario and banks use their own models, subject to a predefined methodology prescribed by the EBA, to develop stress test projections. As everything, this entails both advantages and disadvantages. On the one hand, it ensures a level playing field, with results comparable across banks, supporting their risk-management capacity by allowing them to consider how adverse circumstances may affect the institution's solvency. On the other hand, the approach leaves banks with substantial leeway to underestimate their vulnerability to adverse circumstances.

Bottom-up stress tests are thus enriched with top-down exercises carried out by the ECB and the European Systemic Risk Board (ESRB), to ensure the quality of results, identify system-wide vulnerabilities and inform supervisory actions.

Top-down perspectives are applied in macroprudential stress testing, which focuses on the system-wide impacts of adverse shocks while ensuring that all banks in the system are treated impartially and consistently. Macroprudential stress tests adopt the dynamic balance sheet assumption, enabling the model to account for amplification effects that the banks' reactions to the initial shock may entail at the aggregate level, thus capturing a comprehensive view of the risks embedded in the banking and economic systems. [9]

Stress tests are now being conducted to assess the risks posed by climate change on the whole economy and the financial system, evaluating the resilience of firms, banks and portfolios to climate related externalities. These exercises provide a structured framework to assess how physical and transition risks affect the value and performance of assets, portfolios and financial institutions under different climate scenarios, assessing the resilience of the economic and financial system and informing regulatory activities and risk management practices.

Climate stress tests are currently being conducted by central banks worldwide, the ECB included, applying scenario analysis to understand the potential impacts of different climate scenarios on the financial sector and the broader economy.

4.2 Introduction to the ECB economy-wide climate stress test

The results of the first ECB's economy-wide climate stress test have been published in September 2021, showing similar conclusions to comparable local studies carried out by the Dutch (2018) and French (2020) central banks.

This is an economy-wide climate stress test built along four dimensions:

- It is a top-down exercise, as it relies on data, assumptions and models developed by the ECB staff, thus ensuring transparency and replicability.
- It is a granular exercise that analyses banks' credit and market portfolios at exposure level.
- The scope is unprecedented, encompassing 4 million corporates worldwide and 1600 consolidated banking groups throughout the Euro area.
- It analyses the interactions between transition and physical risks over a 30-year time horizon, considering both the direct and indirect impact on firms and banks of the more

severe and frequent natural disasters, allowing to compare the costs and benefits of climate policy action.

Like traditional stress tests, which investigate how bank liquidity and capital would be affected under a number of severe, but plausible, scenarios of potential future events, climate stress tests have the objective of testing the resilience of banks and non-financial corporations (NFCs) in a range of climate scenarios, which combine plausible representations of future climatic conditions with estimates of the macroeconomic impact of policies designed to limit the extent of climate change.

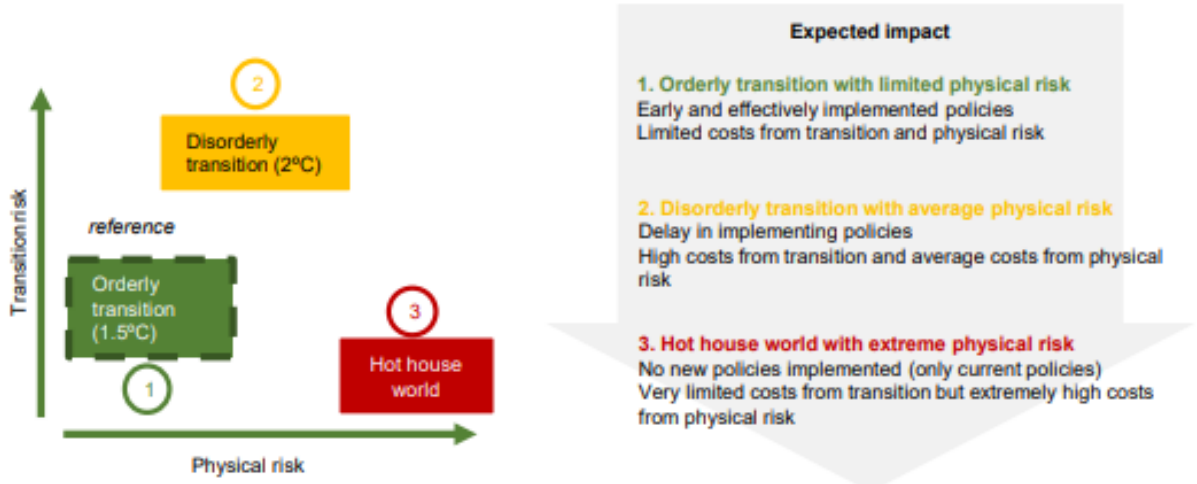
On the one hand, the stress test assesses the impact of climate-related risks on the profitability and solvency of non-financial corporations (NFCs), by translating climate risk drivers into common balance sheet indicators and considering the effects on firms' probabilities of default (PDs) through changes in their profitability and leverage. On the other hand, it investigates how these balance sheet changes in the non-financial sector affect banks' portfolios.

Variables used to account for the impact of transition risks on NFCs include the evolution over time of carbon costs, energy efficiency and technological change. For physical risks, estimates are computed on the future damages from natural catastrophes and their potentially disruptive effects on firms' production. Furthermore, the role of mitigants is reflected by accounting for corporates' insurance coverages.

4.3 Climate scenarios

This ECB's economy-wide climate stress test considers three main scenarios, which differ from each other in their levels of transition and physical risks and are based on the scenarios developed by the Network for Greening the Financial System (NGFS), a global coalition of central banks and supervisors established in 2017 to address the challenges posed by climate change to the financial sector and to promote sustainable finance.

Figure 2 – Representation of the three scenarios in terms of physical and transition-risk levels



Source: ECB

The baseline scenario (in green in Figure 2), that will serve as a reference for comparing the effects of alternative adverse scenarios, is characterized by an orderly transition, where climate policy measures are well calibrated and implemented in a timely and effective manner, leading to relatively limited costs associated with transition and physical risks. This is the only scenario that meets the Paris Agreement target of keeping the global temperature increase "well below 2 degrees Celsius by 2100".

The most adverse scenario (in red in Figure 2) is referred to as the "hot house world", characterized by no regulation or policy aimed at limiting climate change, leading to extremely high physical risks. Transition costs are very limited, as there is no actual transition, and physical costs are extremely high. Global warming is projected in the order of (at least) 3 degrees Celsius above pre-industrial levels by the end of the century, thus not meeting the Paris Agreement's targets.

In the middle (yellow in the figure) we find the third and last scenario, referred to as “disorderly transition”, that assumes a delayed and abrupt introduction of mitigation policies (from 2030), increasing both physical and transition risks when compared with the baseline case.

These scenarios play out over a 30-year time horizon, allowing to keep prediction intervals within reasonable limits while making it possible to assess the long-term impact of climate change risks. Firms are assumed to adapt over time to time-varying policy conditions through adjustments in their carbon footprint (CO2 emissions).

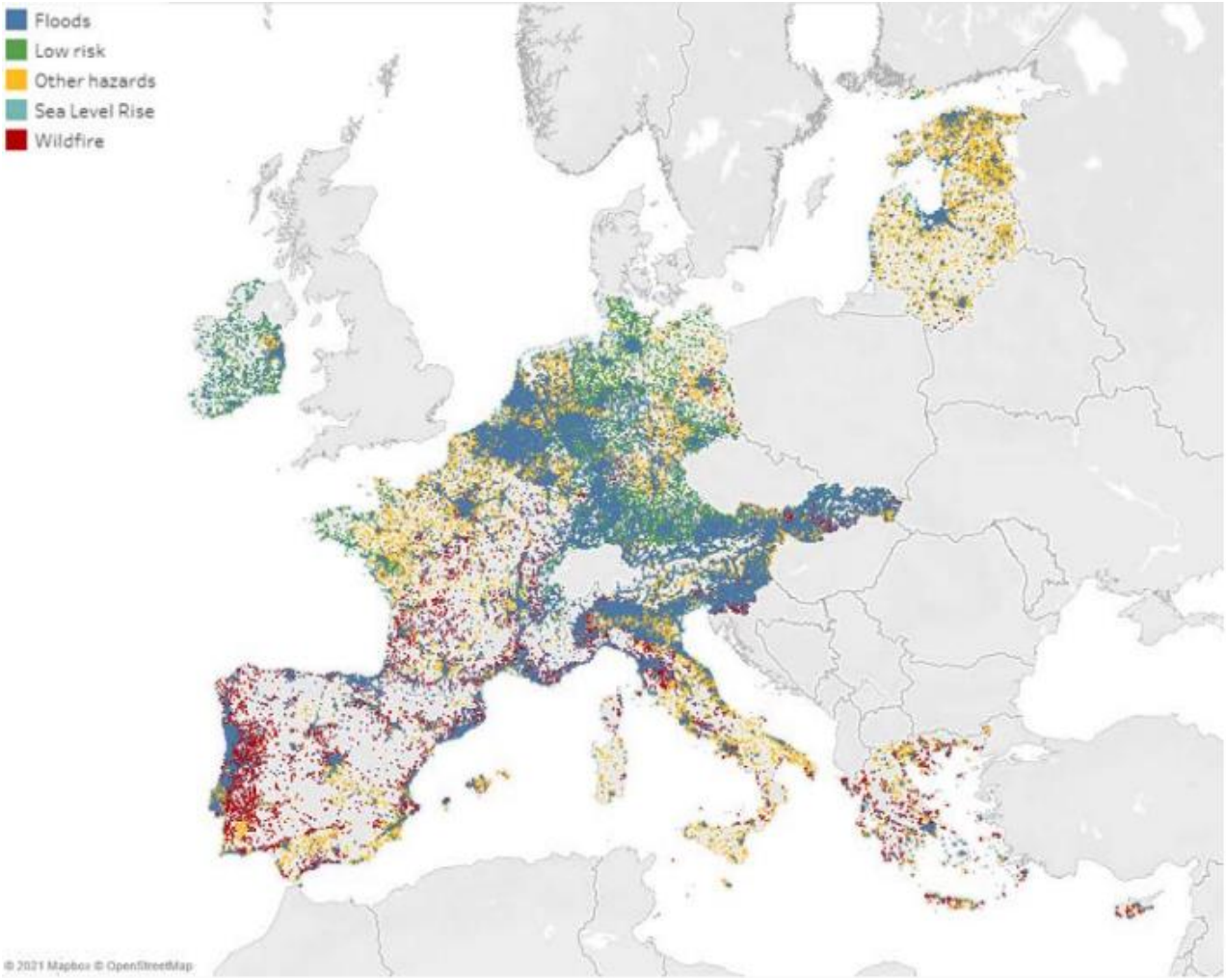
4.4 Physical and transition risks

As anticipated, the study first analyses the exposure of European firms to physical and transition risks. These are the two channels through which climate change affects the functioning of our economy.

The physical risk of a changing climate consists of extreme and more frequent weather events such as floods, droughts, wildfires and storms, that pose risks to human and natural systems. Physical risks also include changes in temperature and precipitation patterns, that are becoming more variable in their timing and intensity.

Figure 3 shows the distribution and intensity of climate physical risks across Europe. The ones of most interest are wildfires, flooding and sea level rise, frequently referred to as location-specific because they affect different regions in different ways, causing a non-linearity in the economy’s exposure to physical risks. Other hazards include heat stress, water shortages, hurricanes and earthquakes, which tend to have more distributed impacts over the economy. Considering the European case, the southern regions are more exposed to wildfires and droughts, while central and eastern areas suffer more from the risk of floods.

Figure 3 – Intensity and sources of physical risk across European regions



Source: ECB (2018)

Transition risks, instead, arise from the shift towards the carbon-neutral economy needed to limit global warming below 2 °C above pre-industrial levels. Carbon-neutrality refers to an economic system where the amount of greenhouse gasses (GHG) released into the atmosphere is being balanced by the removal or off-setting of an equivalent emissions amount, so that the net quantity of CO2 and other greenhouse gasses added in the atmosphere is zero, resulting in no additional contributions to climate change from human activities. [10]

Shifting towards a carbon-neutral economy requires significant reductions in GHG emissions. This is something that is expected to be achieved through various channels, including carbon offsetting technologies, policy and regulation-pushed mitigation efforts as well as technological innovations. All these measures introduce so-called transition risks, that affect different sectors to various degrees.

Economic activities that are heavily reliant on fossil fuels, such as mining, agriculture, electricity and gas, as well as the actual fossil fuel extraction, are more exposed than others to potential disruptions, due to the implementation of effective carbon pricing mechanisms (carbon taxes), and to a shift towards renewable energy sources.

Both physical and transition risks affect inflation, economic growth, financial stability and monetary policy transmission, as well as the risk embedded in various asset categories.

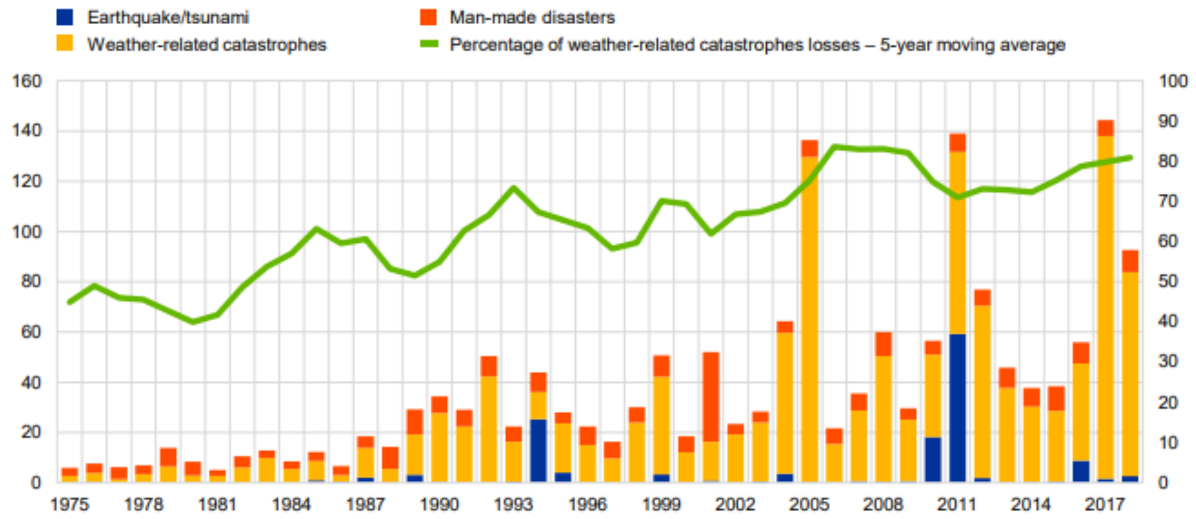
The costs associated with climate change, even in the near term, appear inevitable either in the form of direct physical impacts of climate-related shocks, or transition costs associated with mitigation policies, or both.

On the one hand, available estimates from the OECD (Organization for Economic Cooperation and Development) suggest that climate-change related physical damages could reach one tenth of global GDP by the end of the century, with clear and considerable uncertainties around amplifying dynamics without the development of mitigation policies.

On the other hand, according to available estimates the transition to a low-carbon economy would require between 1 and 4 trillion USD in constant terms when considering the energy sector alone, and up to 20 trillion USD when looking at the broad economy. While such investments entail upfront costs, they may also embed positive benefits associated with employment or output multipliers, as well as productivity gains stemming from the adoption of new technologies.

The economic costs of physical damages stemming from climate change have been growing steadily in recent years, particularly for insurance corporations in the EU. Figure 4 shows the insured losses coming from different risk sources, including earthquake/tsunami and weather-related catastrophes. Meteorological and hydrological events represent over 80% of catastrophe-related losses, as of 2018. What's important to notice here is how physical and transition risks are already playing a growing role in eroding the collateral and assets values of insurance corporations.

Figure 4 – Global insured catastrophe losses (Left-hand scale: USD billions in 2018; right-hand scale: percentages)



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

From the analysis of academic and policy literature on climate change costs, we understand that both policy action and inaction entail high costs, thereby creating no simple solutions, but rather a series of trade-offs that stem from the timing and stringency of action.

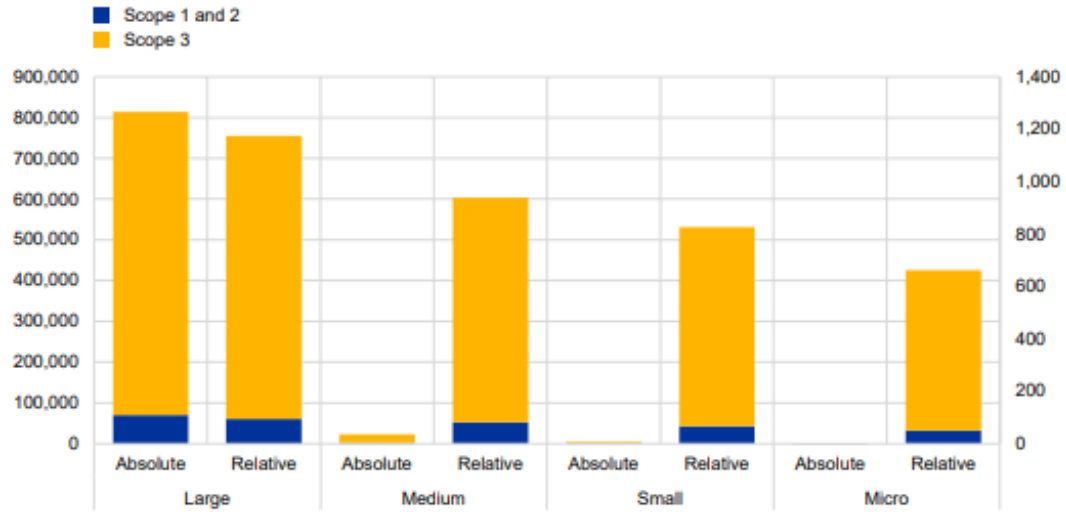
4.5 Non-Financial Corporations exposures to climate risks

As said, the exposure to extreme weather events and natural disasters varies significantly across countries and types of hazards, with southern European regions expected to suffer more from wildfires and countries located in eastern and central Europe more prone to flooding risks.

The exposure to transition risks is also heterogeneous, in this case with significant differences across sectors and firm dimensions.

Figure 5 classifies firms in four different size categories based on their amount of total assets and presents ECB's findings about their average emission intensities. It clearly shows that micro firms are almost half as carbon intensive as large firms, emitting around 600 t/CO2e compared to 1100 t/CO2e per euro in revenues.

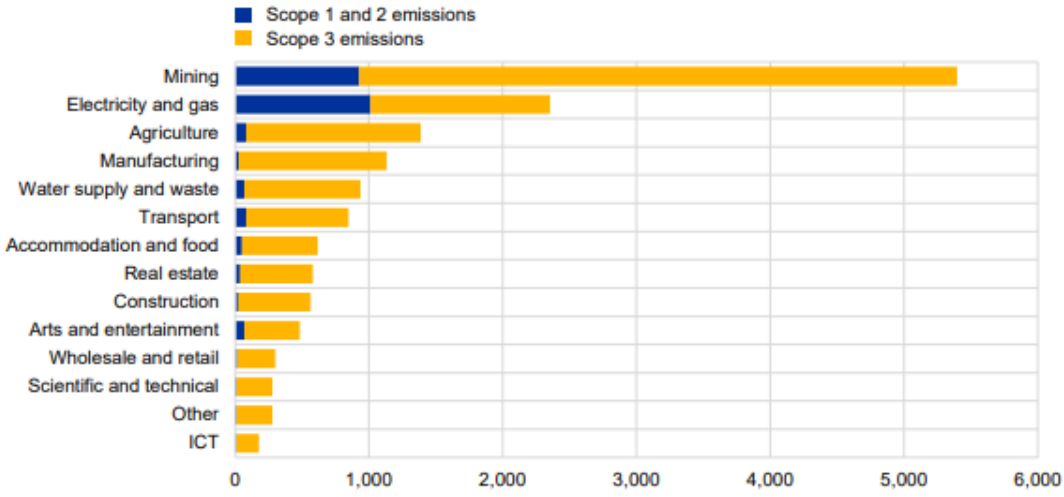
Figure 5 – Emissions by firm size (left-hand scale: t/CO2; right-hand scale: t/CO2 per EUR)



Source: ECB calculations based on AnaCredit, Orbis and Urgentem data (2018)

Average emission intensities also vary wildly across different sectors, with mining, electricity and agriculture being at the top of the list, as shown in Figure 6. Still, the biggest contributors to overall absolute emissions are manufacturing, electricity and gas, and transportation.

Figure 6 – Emissions by sector (t/CO2 per EUR)



Source: ECB calculations based on Urgentem data (2018)

It is thus clear that firms most exposed to transition risks are concentrated in specific resource-intensive sectors, including mining, electricity and gas, agriculture, water supply and waste.

It is also important to clarify how emissions are calculated and their breakdown. As shown in figure 5 and 6, there are three categories of greenhouse gas emissions, known as the “three scopes”, associated with different activities and sources.

Scope 1 emissions are direct greenhouse gas emissions from sources that are owned or controlled by the reporting entity. They include the on-site combustion of fossil fuels (such as natural gas for heating or gasoline for company-owned vehicles) and production processes’ direct emissions.

Scope 2 emissions refer instead to indirect greenhouse gas emissions resulting from the generation of energy off-site but consumed by the reporting entity. They include emissions associated with electricity and heat or steam that are purchased by the reporting company but produced somewhere else. They are indirect emissions as the reporting entity doesn’t directly control them.

Scope 3 emissions include all other indirect GHG emissions that occur along the value chain of the reporting entity. They are typically beyond the entity’s control and include emissions from upstream and downstream activities (such as the extraction, production and transportation of purchased goods and services), from the use and final disposal of products sold and from employees’ business travel.
Scope 3 often represents the largest emission category for an organization, mainly out of its control.

Unlike for physical risks, average differences in emissions are not very pronounced at the country-level, leaving a homogeneous exposure to transition risk for the different European countries.

As said, the climate stress-test objective is to assess the impact of climate-related risks on the profitability and solvency of NFCs under the three different scenarios, while allowing for the role of mitigants and amplifiers.

The effects of transition risk on the main components of firms’ profitability (revenues and operating costs) and leverage are both supply and demand driven.

On the supply side, changes in production costs are driven by carbon prices that affect firms’ operating expenses proportionally to their Scope1 emissions, as well as the energy costs, which increase as a function of Scope2 emissions. Moreover, energy costs are influenced by the energy transition at the country-level, which determines the energy mix, as well as by movements in energy prices coming from technological developments and global markets.

On the demand side, transition risks are captured by modelling the impact of carbon price on the sale of carbon-intensive goods. Thus, firms' revenues may decline as a function of their Scope3 emissions intensity.

To conclude, firms' leverage is expected to increase due to the replacement of existing production processes and the switch towards more environmentally friendly technologies, as well as to the debt incurred to cover physical damages.

Moving to physical risks, the modelling framework computes the direct and indirect effects of firms' exposure to extreme weather events to determine the expected loss to physical capital. Results show that damages are expected to be the highest in the hot house world scenario and disorderly transition, when compared with the orderly transition case, confirming that physical risks have the potential to drive financial instability.

The ECB's economy-wide stress test thus concludes that the median European firm is expected to have a higher profitability, lower indebtedness and thus lower probability of default if an orderly transition takes place. Capital losses and lower profitability lead to poorer financial conditions for European firms in both adverse scenarios. Particularly, if no transition takes place, probabilities of default are expected to be 6% higher in 2050 and profitability to drop by almost 40%, when compared with the orderly transition scenario. Thus, the short-term costs of an orderly transition are more than offset by the long-term benefits of climate change mitigation policies.

Of course, high-emitting firms (the top 10% of firms with the highest intensity of emissions), are characterized by higher transition risk. Transition risk appears to be heavily concentrated in agriculture, mining, manufacturing and electricity and gas, which, while constituting 18% of the sample, account for almost 70% of the high-emitting firms.

Higher transition risk is reflected in higher leverage and greater volatility of outcomes across the scenarios: high-emitting firms will have to raise substantially more debt during the transition to replace existing technologies with more environmentally friendly ones and will suffer greater reductions in their profitability because of carbon taxes. Still, the orderly transition scenario is associated with better performances both in terms of leverage and profitability, which translates in lower default probabilities.

Firms that are exposed to high physical risk would logically benefit from an orderly transition. In fact, they would suffer strong increases in their leverage over the medium to long run due to

physical damages without the timely implementation of mitigation policies. Alongside, their profitability would likely decrease, as a consequence of higher insurance premia to protect against natural disasters.

4.6 Banks exposures to climate risks

Moving to the banking sector, the ECB's economy-wide stress test analyses around 1600 banks, covering up to 80% of the bank loans held in the Euro area. Climate risk is transferred to the banking sector though their loan and bond exposures to NFCs, through the so-called credit and market-risk channels.

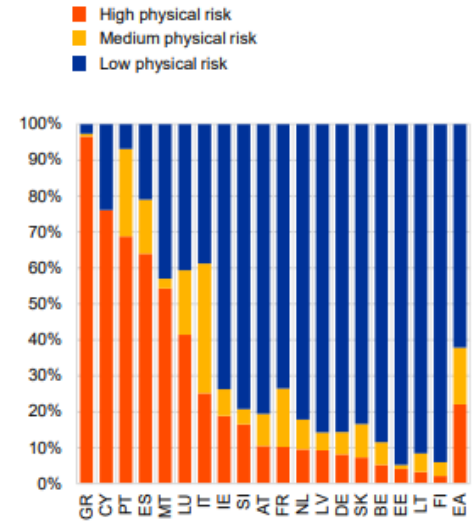
4.6.1. Credit risk channel

We will first analyze the credit (risk) channel.

European banks have a strong home bias, with a tendency to provide loans predominantly to domestic firms, something reflected in the fact that almost 80% of banks' exposures in the Euro area are towards firms located in their origin country. This percentage of domestic versus foreign exposures determines the extent to which the country-level climate risk of non-financial corporations translates into country-level climate risk for the banking sector.

Figure 7 distinguishes between high, medium and low physical risk exposures for euro area loans. High physical risk is attributed to those firms (and thus loan exposures) for which the probability of suffering from a wildfire, river or costal flood in a given year is more than 1%, while the risk is categorized as low when that probability is lower than 0.1%. Combining this information with the fact that, on average, European banks keep almost 80% of their exposures towards domestic firms, Figure 7 shows how also banks' exposures to physical risk depend greatly on their location: banks located in south European countries are significantly more exposed to firms that are subject to high physical risks, when compared to the Euro area average.

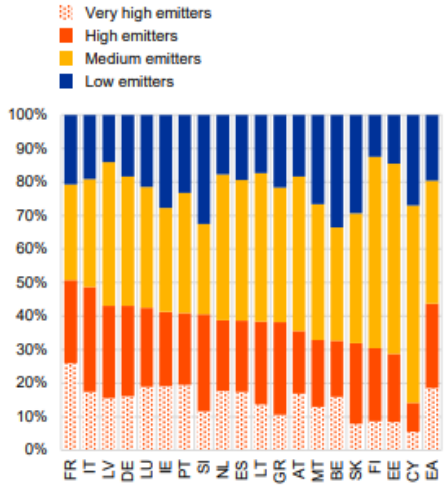
Figure 7 – Share of bank loans exposed to physical risk



Source: ECB calculations based on AnaCredit, Urgentem, and Four Twenty Seven data (2018)

On the other hand, banking sector's exposures to transition risk seem to be comparable across all European countries, as shown in Figure 8.

Figure 8 – Share of bank loans exposed to transition risk

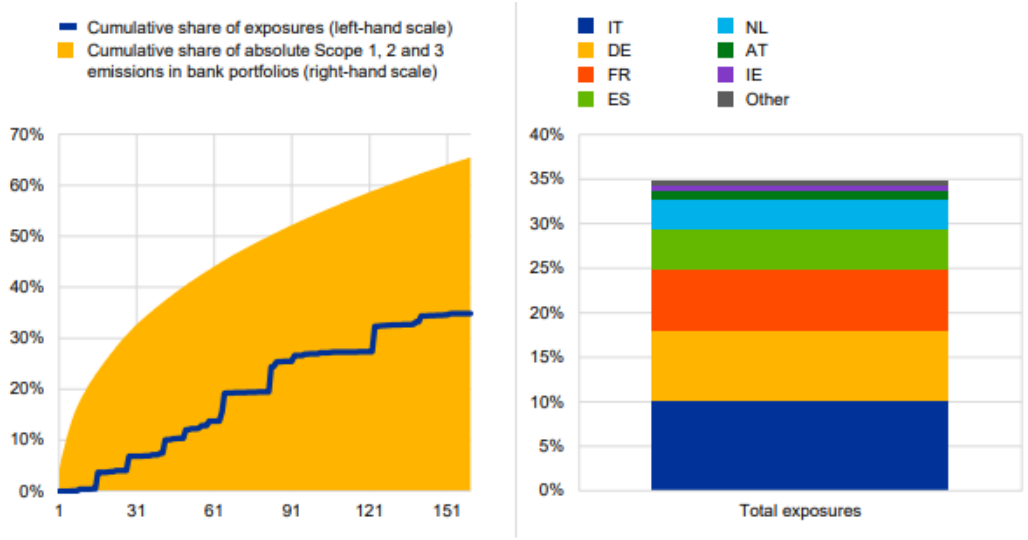


Source: ECB calculations based on AnaCredit, Urgentem, and Four Twenty Seven data (2018)

Still, tail transition risk is concentrated in specific banks and countries. Figure 9 shows how the top 10% most polluting portfolios, which represent 30% of the overall exposures in the Euro area, finance up to 65% of total emissions, with Italy, Germany and France being the countries where most of these portfolios are located.

The left panel presents the cumulative share of exposures and emissions of the top 10% most polluting banks, while the right one shows the country composition of the top 10% of most polluting banks.

Figure 9 – Share of exposures subject to high transition risk



Source: ECB calculations based on Four Twenty Seven and AnaCredit data (2018)

Under the different climate scenarios, changes in the probability of default (PD) and loss given default (LGD) of banks' loan books are computed to determine the impact on banks' credit risk. Firm-level default probabilities are translated into bank's loan book probabilities of default, based on the composition of banks' portfolios, thus considering the weighted exposure the bank has to each NFC.

ECB's findings on the banking sector show similar results to what already said for non-financial corporations: banks would suffer the cost of a green transition in the short run, with this effect being reversed in the medium to long term when the economic benefits of an orderly transition outweigh the costs.

In the hot bouse world scenario, default probabilities would be 1.5% lower than in the orderly transition up to year 2030. This would totally reverse over time, with the median loan portfolio's PD being 7% higher than baseline by the year 2050.

Moreover, the ECB study distinguishes between different type of banks, classifying them as Global systemically important banks (G-SIB), Significant institutions (SI) and Less-significant institutions (LSI), sometimes referred to as Non-significant institutions (Non-SI). On the one hand, Global systemically important banks are those whose failure would trigger a wide-spread financial crisis

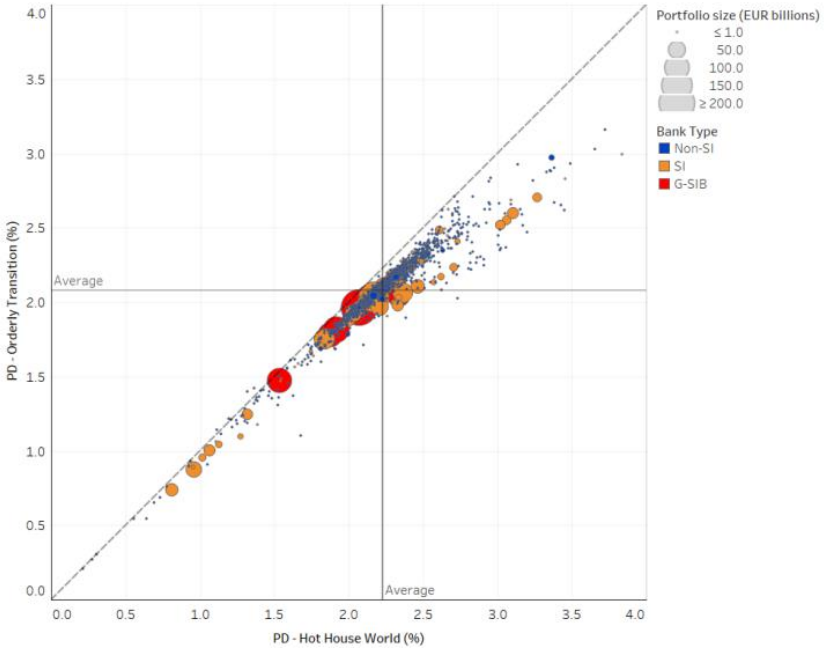
and threaten the global economy. On the other hand a bank is considered significant (and therefore under direct ECB's supervision) if it fulfills at least one of the following criteria:

- Total assets value exceeding Eur 30 billion.
- It is economically important for the specific country of for the EU economy as a whole.
- The total value of its assets exceeds Eur 5 billion and the ratio of its cross-border assets/liabilities in more than one other participating member state to its total assets/liabilities is above 20%
- It has requested or received funding from the European Stability Mechanism or the European Financial Stability Facility.
- It is one of the three most significant banks established in a particular country. [10]

In particular, Figure 10 illustrates a comparison between the orderly transition and the hot house world scenario in terms of banks' default probabilities (PD), distinguishing between Global systematically important banks (G-SIB), significant institutions (SI) and non-significant institutions (Non-SI).

In the chart, virtually all banks, except for a few small ones (Non-SI) are located below the diagonal line, which means they are expected to have their PDs relatively higher under a hot house world scenario compared to the orderly transition.

Figure 10 – probabilities of default by 2050: orderly transition (Y-axis) versus the hot house world (X-axis)



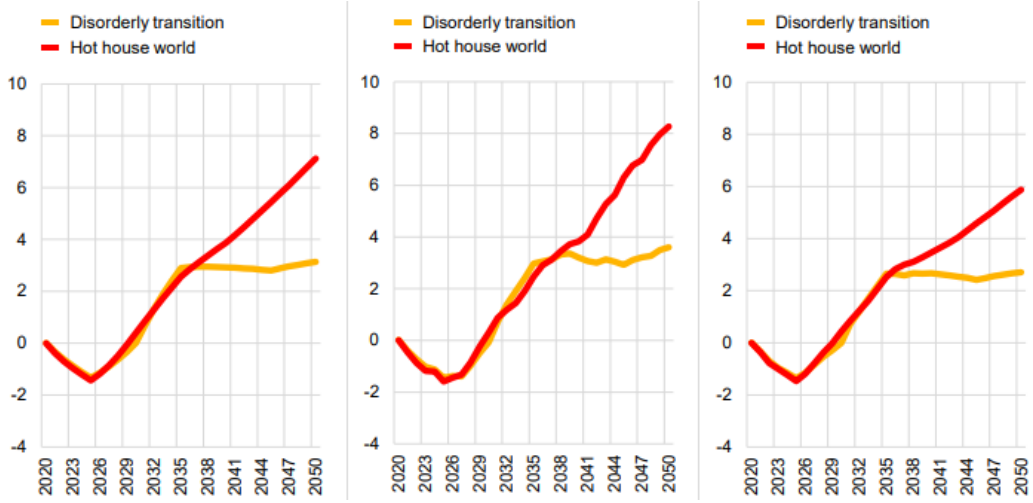
Source: ECB calculations based on NGFS scenarios (2020), Anacredit, Orbis, Urgentem and Four Twenty Seven data (2018)

Results thus show how nearly all banks would benefit from an orderly transition as compared with the hot house world scenario by 2050.

Another interesting finding, as shown in Figure 11, is that significant institutions (SIs) are more severely affected in a non-transition scenario. The charts below display the median percentage changes under the disorderly transition and hot house world scenarios relative to baseline (orderly transition), showing that significant institutions see their median PDs about 2% higher than less significant institutions (LSIs) by 2050.

The left-hand panel shows data for the entire sample, the right-hand one for LSIs, while in the middle we have SIs.

Figure 11 – Probabilities of default: percentage changes relative to baseline scenario



Sources: ECB calculations based on NGFS scenarios (2020), AnaCredit, Orbis, iBACH, Urgentem and Four Twenty Seven data (2018)

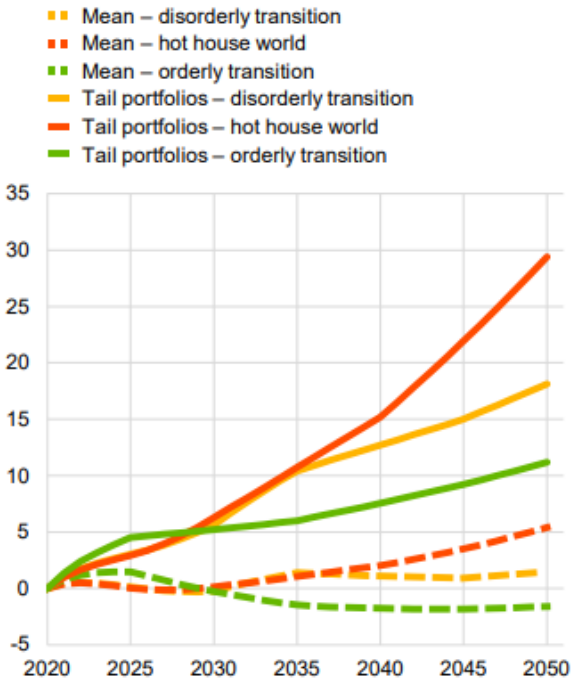
The impact on banks' corporate credit books in a hot house world scenario would be not only higher but also non-linear, with particularly severe effects in certain geographical areas (and thus on certain banks, as their exposures tend to be local). Some countries would experience a disproportionally larger deterioration in banks' loan portfolio PDs compared to the rest.

This can be seen in Figure 12, which shows changes relative to the start period (2020) for the median portfolios and for the top 10% of banks with the largest dispersion, in the three tested scenarios.

Tail-banks, meaning the top 10% of banks in terms of PD dispersion, would experience PDs rising to 30% by 2050 in the non-transition scenario.

Those are mainly banks located in countries more vulnerable to physical risks. They would also face a long-term increase in average PDs under the transition scenario, something substantially different from the mean results of the entire sample, where there is a clear benefit in terms of PDs reduction with an early transition.

Figure 12 – Projected probabilities of default of banks' corporate loan books



Sources: ECB calculations based on NGFS scenarios (2020), AnaCredit, Orbis, Urgentem and Four Twenty Seven data (2018)

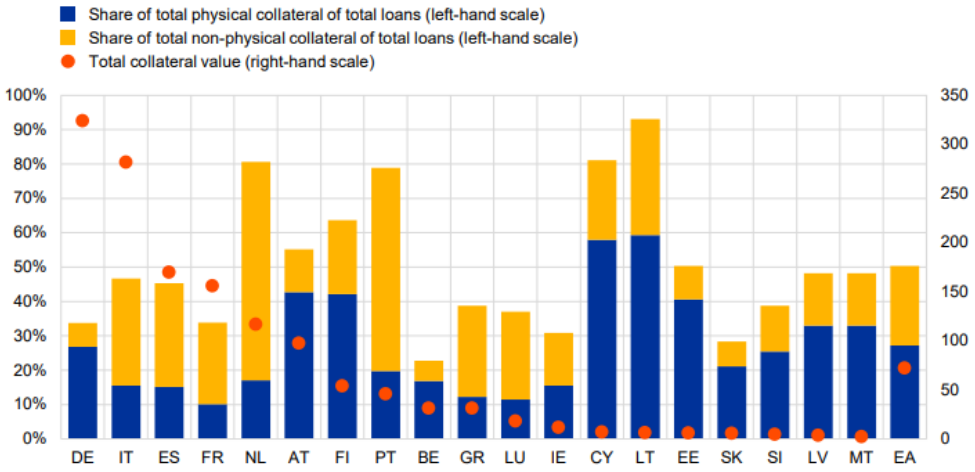
Moving now to LGD (loss given default), this represents the estimated amount of money a bank (or any other financial institution) would lose if a borrower defaults on a loan.

In this study, the impact of climate change on bank's corporate loan portfolios' LGD is modelled though a micro and a macro channel.

The first one captures the deterioration in the value of the physical collateral, stemming from damages related to physical risks. The second accounts for changes in LGD due to macro-financial shocks, focusing on changes in GDP stemming from the transition and physical risks of the different scenarios. The sum of both channels provides the total change in LGDs for each bank loan.

Figure 13 shows how approximately 50% of the analyzed loans are protected by collateral, with significant differences across countries, and most of the collateral being represented by physical assets.

Figure 13 – Share of loans protected by physical and non-physical collateral



Left-hand scale: share of physical and non-physical collateral (percentages); right-hand scale: total collateral (EUR billions)

Sources: ECB calculations based on AnaCredit, Orbis, Urgentem and Four Twenty Seven data (2018)

The impact on corporate credit portfolios' LGDs is mainly driven by damages to physical assets over the 30-year time horizon, with the highest impact in the hot house world scenario. In such a case, the non-linear nature of physical risk would affect bank portfolios in some countries disproportionally more than in others.

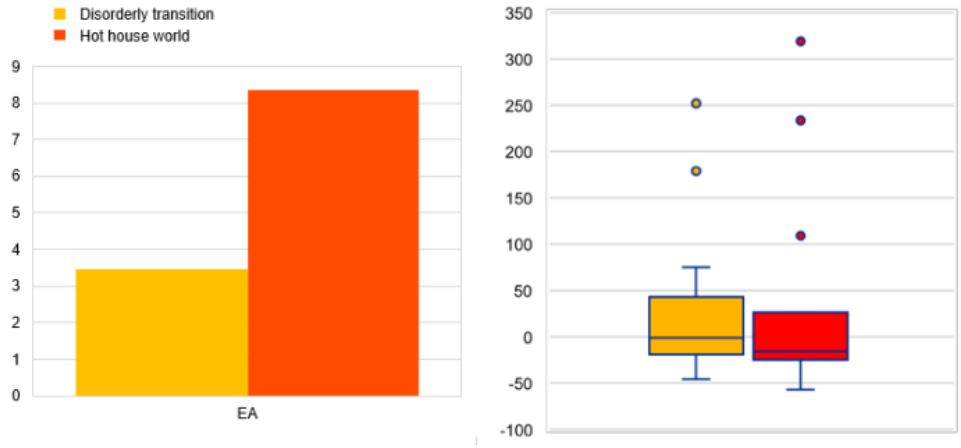
Combining climate-stressed PDs and LGDs of banks' corporate loan portfolios, expected losses for the banking sector are computed by multiplying the loan amount (for each climate scenario, bank and NFC) with its specific LGD and PD. Total losses for each bank portfolio and scenario are then derived by adding up the loan-specific expected losses of their counterparties.

Such expected losses are minimal in the event of an orderly transition, as they are mainly driven by physical risks which diverge the most between scenarios. On the contrary, in the two adverse scenarios, significant deviations from baseline are expected.

Figure 14 represents the distribution of expected losses by 2050, showing how these are more than 3% higher than baseline in the disorderly transition, reaching about 8% in the hot house world.

The right panel of the figure instead focuses on the distribution of country-level deviations from the Euro area average, confirming the non-linearity of physical risks distribution across different regions.

Figure 14 – Distribution of expected losses by 2050 (percentages)



Sources: ECB calculations based on NGFS scenarios (2020), AnaCredit, Orbis, Urgentem and Four Twenty Seven data (2018)

4.6.2. Market risk channel

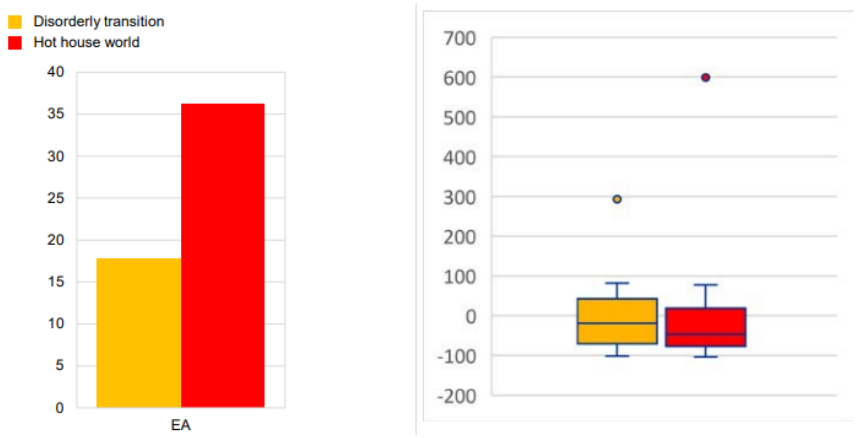
Moving to the market (risk) channel, this accounts for the impact of climate change on banks' corporate bond portfolios, through the sensitivity of securities' prices to movements in market-risk factors due to climate risks.

Shocks on credit spreads from transition and physical risks under the different climate scenarios are estimated though an internal ECB model.

Findings show that the impact of market risk is relatively limited as compared with the credit-risk channel, while following similar dynamics in terms of country and scenario differences. Figure 15 presents the distribution of market losses between 2020 and 2050 relative to baseline.

The left-hand panel of the figure focuses on euro area average change in bank-level expected losses between the two adverse scenarios and the baseline, while on the left is the distribution of country-level deviations from the euro area average.

Figure 15 – Distribution of market losses between 2020 and 2050 relative to baseline (percentages)



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

4.7 Conclusions

The ECB exercise in still not comprehensive. This is true for several reasons:

- It assumes banks' exposures and portfolio composition to remain fixed over the entire timeframe.
  This doesn't allow to account for second-round effects and potential feedback loops between banks and the real economy.
- It doesn't account for other financial intermediaries, such as insurance corporations and asset managers, that play an important role in terms of climate risk mitigation and/or amplification.

Still, this first economy-wide stress test shows that there are clear benefits to acting early. The short-term costs of an early and orderly transition clearly outweigh the medium to long term damages of unaddressed physical risks. In fact, results show that, if left unchecked, physical risks become increasingly higher over time, in a non-linear fashion, affecting NFCs probabilities of default, and thus representing a major source of systemic risk, particularly for banks with portfolios concentrated in certain economic sectors and geographical areas. [12]

5. Climate change's upward price pressures and market instability

The ECB's economy-wide climate stress test is just one of the steps the ECB is taking to tackle climate change. It shows that the ECB is starting to integrate climate-change considerations into its macroprudential policy framework, assessing the resiliency of the banking system (and of the economy as a whole) towards climate risks, and providing useful data and information to the financial sector.

The ECB recognizes that climate change introduces significant risks to financial and price stability. This is one of the least explored aspects of climate change but not the least important. In fact, climate change has the potential to disrupt supply chains (mainly as a result of physical risk), increase production costs (due to both physical and transition risks), resulting in increased market volatility and price pressures.

Climate change can contribute to financial instability and price pressures in several ways:

- Agricultural impacts: shifts in temperatures and precipitation patterns lead to crop failures and lower yields, affecting food prices due to negative supply shocks. A World Bank study estimates a reduction of 5% in global crop yields already by 2030 due to climate change. [13]
- Extreme weather impacts: extremes weather events such as floods, droughts, hurricanes and wildfires are exacerbated by climate change. These events damage infrastructure and transportation networks, thus leading to increased production costs and supply shortages, that translate in upward price pressures.
- Resource scarcity: resources such as water and forests, particularly in exposed geographical areas, are threatened by climate change. Diminishing resources increase competition among industries and nations. Taking the example of water scarcity, this affects sectors such as agriculture, energy, and even manufacturing. Again, reduced resources and greater competition over them translate into upward price pressures.
- Regulatory changes: climate policies introduced by governments worldwide to reduce greenhouse gas emissions and increase sustainability introduce compliance costs for the private sector. The best example is the carbon tax (or other carbon pricing mechanisms), that translates into increased production costs especially for industries that are heavily reliant of fossil fuels.

All these factors contribute to upward price pressures and market volatility, they affect macroeconomic variables such as output and inflation, as well as investments and productivity, affecting the value and risk profile of the assets held on the Eurosystem's balance sheet, and jeopardizing price stability and the smooth transmission of monetary policy.

For this reasons, central banks, and in particular the ECB, are starting to consider the impact of climate change and how to adapt their monetary policy operations to account for sustainability factors.

6. Monetary policy tools and related changes to account for climate change considerations

There are several types of monetary policy operations, also referred to as "tools" in the hands of the central bank, used to reach the ECB's primary mandate of price stability, which is, to preserve the value of the Euro.

The ECB currently defines price stability as "2% inflation over the medium term", highlighting how the target is symmetric, meaning that fluctuations above or below the value are considered as equally undesirable.

The monetary policy stance, as well as the tools used to achieve it, are determined by the ECB's Governing Council, which consists of the six members of the ECB's Executive Board, plus the governors of the National Central Banks of the twenty euro area countries.

We will here analyze the main monetary policy tools used by the ECB and the changes implemented to account for climate change considerations.

6.1 Conventional monetary policy tools

Interest rates are the most common and important monetary policy tool: to tighten financial conditions the central bank will increase rates, while for a monetary policy easing it will decrease them. Interest rates is a general term. What the ECB directly controls are three policy rates:

- The interest rate on the main refinancing operations (MROs), also known as the "cost of money", which normally provide the bulk of liquidity to the banking system and represents the most important policy rate in Europe.
- The interest rate on the deposit facility
- The interest rate on the marginal lending facility

These three policy rates create the so-called "ECB's interest rate corridor", with the marginal lending facility rate acting as upper bound, the deposit facility rate as lower bound and the MRO rate being in the middle.

The two standing facilities, managed in a decentralized manner by the National Central Banks (NCBs) of the Eurosystem, are set to provide and absorb overnight liquidity, signal the monetary policy stance and bound overnight market interest rates.

The deposit facility allows counterparties to make overnight deposits at the National Central Bank, providing a floor to overnight market interest rates, because banks would have no incentive to lend liquidity in the interbank market at rates that are lower than the ones they can get at the NCB.

On the other hand, the marginal lending facility allows counterparties to obtain overnight liquidity from the National Central Bank against eligible assets (thus providing some collateral). The marginal lending facility rate usually acts as a ceiling for overnight rates, because a bank will turn to this facility only if it can't find cheaper liquidity on the market.

Main refinancing operations fall in the Open Market Operations (OMOs) category, which, together with minimum reserve requirements for credit institutions and standing facilities, make up for the conventional monetary policy tools in the hands of the European Central Bank.

6.2 Open Market Operations

Open Market Operations consist in the buying and selling of (mainly bond) securities by central banks in the open market, meaning that all commercial banks can take part in these operations. They can be carried out in the form of outright operations (definitive purchases of assets by the ECB) or securities repos, where the central bank purchases assets from the banking sector with a simultaneous agreement to repurchase at a later date. In their role as a monetary policy tool, OMOs contribute to the achievement of price stability, they help anchoring inflation expectations and support the functioning of the Euro area money market.

In fact, by adjusting the liquidity conditions in the market, OMOs maintain the operational framework of monetary policy and influence short-term interest rates. Moreover, Open Market Operations play a crucial role in managing inflation expectations and anchoring long-term interest rates. This happens through several channels:

- Interest rate channel: by (for instance) lowering short-term interest rates, the central bank is able to encourage borrowing and investment, thus stimulating economic activity and potentially raising inflation expectations.
- Liquidity channel: OMOs inject or subtract liquidity from the financial system. Injecting liquidity through asset purchases, for instance, increases the money supply, potentially leading to higher spending and inflation expectations.

- Portfolio rebalancing channel: when government securities in banks portfolios are replaced with reserves or cash, this can lead to portfolio rebalancing, potentially leading investors to seek higher-yielding products.

Moreover, the implementation of Open Market Operations by the central bank conveys important signals about its monetary policy stance. To make an example, asset purchases during periods of economic weakness signal an accommodative stance, stimulating economic activity and supporting inflation expectations.

The Eurosystem conducts Open Market Operations in the form of:

- Fixed rate (volume) tenders, where the ECB specifies an interest rate in advance and participating institutions bid the amount of money they are willing to transact at that rate. Under normal circumstances, if the demand exceeds the planned supply, credit is rationed.
- Variable rate tenders, where counterparties bid both the amount of money and the interest rate at which they want to enter transactions with the National Central Banks.

Main refinancing operations, in particular, are regular liquidity-providing reverse transactions conducted by the Eurosystem with a frequency and maturity of normally 1 week, executed in a decentralized manner by the National Central Banks to manage the liquidity conditions in the Euro area banking system. They provide the bulk of refinancing to the financial sector.

As a condition for participating in MROs, banks are required to provide eligible collateral against the liquidity they receive from the central bank. The collateral framework is periodically updated but tends to be composed of government bonds from Euro area member states, supranational bonds (issued by certain international agencies and supranational organizations), high-quality asset-backed securities (ABS) and certain high-quality corporate bonds (characterized by high rating and liquidity).

6.3 Climate-related changes in the policy framework

In a press release on the 4th of July 2022 the ECB announced a series of measures to actively integrate climate-change considerations into its monetary policy framework. Some of them are related to the collateral framework. [14]

In particular, the Eurosystem will limit the share of assets issued by entities with a high carbon footprint that can be pledged as collateral by individual counterparties when borrowing from the Eurosystem, starting before the end of 2024. This is expected to have the double effect of reducing the climate-related financial risks in Eurosystem credit operations, while creating an incentive for banks to "clean-up" their balance sheets from carbon-intensive exposures.

When evaluating the collateral pledged by banking institutions willing to participate in Open Market Operations, the ECB evaluates the quality and safeness of that collateral by applying haircuts to the value of those assets, based on their riskiness.

Starting in 2022, the Eurosystem will consider also climate change risks when reviewing haircuts applied to corporate bonds pledged as collateral.

Moreover, starting in 2026, the Eurosystem will only accept marketable assets and credit claims from companies and debtors that comply with the Corporate Sustainability Reporting Directive (CSRD) as collateral in Eurosystem credit operations. This requirement will apply to all those companies within the scope of the CSDR, a directive aimed at expanding the scope of sustainability reporting, enhancing the quality and consistency of disclosures.

The Eurosystem holds bonds and securities both for monetary policy reasons and in its non-monetary policy portfolios.

6.4 Monetary policy portfolios

Monetary policy portfolios consist of different types of financial assets that the ECB purchases and/or holds to implement its monetary policy objectives. The main portfolio is the Asset Purchase Program (APP), which includes:

- Public Sector Purchase Program (PSPP). This portfolio contains government bonds issued by Euro area member states and it aims at providing monetary stimulus to support economic activity and maintain price stability by influencing long-term interest rates.
- Corporate Sector Purchase Program (CSPP), which involves the purchase of investment-grade corporate bonds issued by Euro area companies, improving financing conditions for the corporate sector.

- Asset-Backed Securities Purchase Program (ABSPP), which contains asset-backed securities (ABS) issued by Euro area entities. ABS are securities backed by pools of underlying assets, such as loans and mortgages. With this program the ECB aims at enhancing the functioning of the ABS market, thus facilitating the flow of credit to the real economy.
- Pandemic Emergency Purchase Program (PEPP), developed as a response to the Covid-19 pandemic to allow for the flexible purchase of various assets as a mean to address the impact of the pandemic on the economy and financial markets.
- Targeted Longer-Term Refinancing Operations (TLTRO), which consists of loans extended by the ECB to euro area banks at favorable conditions to encourage lending to households and businesses.

6.5 Non-standard monetary policy tools: quantitative easing

The assets that go into these portfolios are usually acquired by the ECB though quantitative easing (QE). This is a (non-standard) monetary policy tool used by central banks to stimulate the economy and fight disinflationary pressures when standard policy tools become ineffective.

QE involves the purchase of financial assets (government bonds or other securities) by the central bank on the secondary market with the aim of lowering long-term interest rates. In fact, creating additional demand for long-term bonds will put upward pressure on their prices, thus lowering the yields (interest rates).

The money used to buy bonds through QE doesn't come from borrowing or government taxation but is created digitally in the form of central bank reserves, which are then transferred to the counterparties from which securities are bought.

On the one hand, lower long-term interest rates make borrowing cheaper, thus stimulating investment and consumption. On the other hand, the liquidity received by banks in exchange for their bonds increases the money supply in the economy, so the availability of credit that should encourage lending.

QE also (indirectly) supports the prices of other financial assets. When banks or asset managers receive cash from the central bank in exchange for their bonds, rather than hold on to that cash, they might invest it in other bonds or financial assets, such as shares, thus propping up their values and making all market participants who own those securities richer. This is known as the wealth

effect: when the value of an agent's portfolio increases, he becomes richer and can thus afford higher current and future consumption, resulting in increased aggregated demand and output for the economy.

Another similar side-effect of QE is known as the balance sheet effect: since the amount that can be borrowed by agents depends on the collateral they can post against the loan, higher asset prices translate into higher collateral value across the economy, enlarging the borrowing possibilities. This results in higher consumption and/or investment, increasing aggregate demand and so output.

When macroeconomic conditions require it, for instance when inflation rises above the desired target, QE is initially stopped and eventually reversed, through what is called quantitative tightening (QT). With quantitative tightening, the bonds purchased during QE are sold to investors, and the money created to buy them in the first place disappears from the system, making the overall amount of money in the economy go down and obtaining the exact opposite effects of QE. [15]

As already stressed, the soundness of the central bank's balance sheet is crucial for maintaining confidence in the institution's credibility as well as to allow for the effective implementation of monetary policy. A robust balance sheet provides the central bank with the necessary tools and resources to conduct open market operations effectively, thus managing liquidity, influencing interest rates and supporting the transmission of monetary policy decisions throughout the economy.

The consequences for financial stability should not be overlooked either: a sound balance sheet allows the central bank to act as a stabilizing force during times of financial distress, providing a backstop to the banking system by supporting its liquidity needs.

It is for these reasons that climate change considerations are being implemented on the corporate bond holdings of the Eurosystem. The Eurosystem aims at gradually decarbonize its corporate bond holdings, following the Paris agreement's objectives. To this end, starting in October 2022, the climate performance of the assets has been taken into account.

To assess the potential impact of climate externalities on the risk profile of its corporate sector holdings, the Eurosystem currently uses climate stress tests with medium to long term scenarios

(such as the economy-wide stress test discussed in the previous chapter) and a climate scoring tool to assess the corporate issuers' performance on a set of climate-related metrics.

6.6 Management of the Eurosystem's monetary policy portfolios

This is relevant for new asset purchases as well as for the management of the existing balance sheet. In fact, starting in March 2023, the Eurosystem is reducing the holdings of its APP (Asset Purchase Program) portfolio at the pace of EUR 15 billion per month and tilting the (partial) reinvestments for the redemptions exceeding the desired balance sheet reduction amount towards issuers with better climate performances in the particular case of the CSPP (Corporate Sector Purchase Program). Better climate performance is measured with reference to lower greenhouse gas emissions, more ambitious carbon reduction targets and better climate-related disclosures, as already discussed in Chapter 3. [16]

The current ECB's tilting approach on the CSPP is flow-based, meaning that reinvestments of corporate bonds are adjusted based on the issuers' climate scores. The main steering tool in this context is the tilting parameter, that is the weight put on the on the climate score in the new purchases allocation framework. With the stop to net asset purchases, and the reduction of reinvestments, a flow-based approach is not sufficient to decarbonize the portfolio at a pace consistent with the ECB's climate ambitions.

An alternative path requires the switch to a stock-based tilting approach, which means that, absent any reinvestment, there will be active reshuffling of the portfolio towards greener issuers.

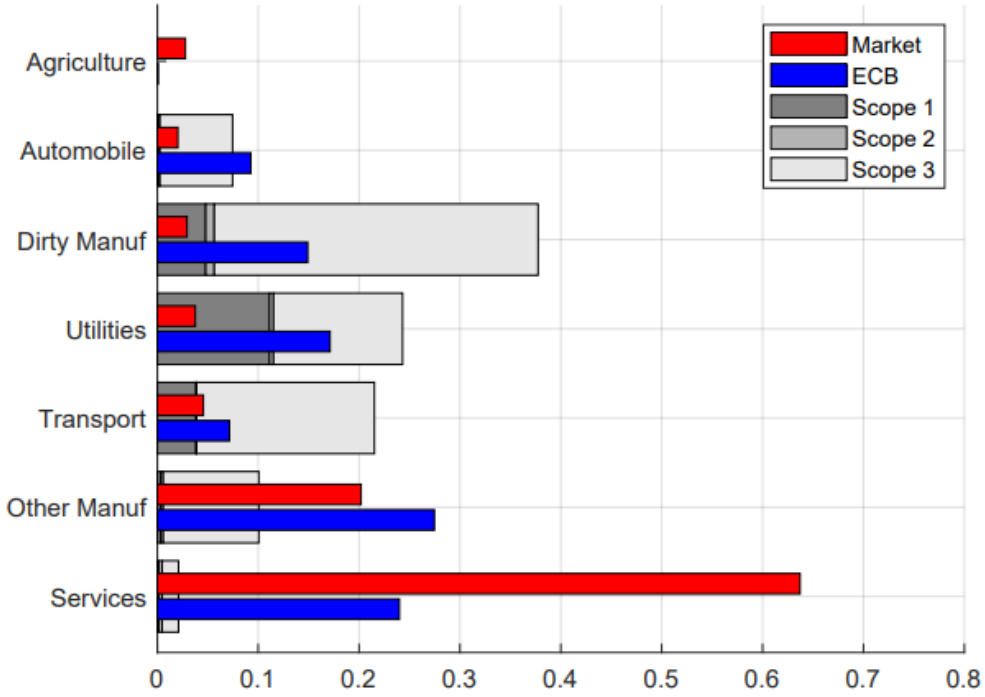
This, on the one hand provides stronger incentives to issuers to improve their disclosures and reduce their carbon footprint, while on the other it allows to further mitigate climate-related financial risks on the Eurosystem's balance sheet.

Providing incentives for firms to decarbonize their activities is, in fact, necessary for the decarbonization of the Eurosystem's portfolio, as this depends both on the tilting parameter and on the pace at which firms decarbonize their businesses. [17]

6.7 Is the current ECB corporate portfolio biased towards high-emitters?

This is especially important when accounting for the fact that ECB's corporate bond portfolio is currently tilted towards high emitting sectors, when compared to the market portfolio of sectoral capital stocks, as shown in Figure 16.

Figure 16 - Sector shares of the market portfolio, ECB's CSPP holdings and emissions



Sources: SHS (ECB), Urgentem, Eurostat

Despite the simplifying hypothesis made to build the market shares, measured as capital income by sector (capital income = value added – wages), Figure 16 provides a clear visualization of the ECB's Corporate Sector Purchase Program overweighting dirty sectors and underweighting clear ones such as services, with data from year-end 2017.

When engaging in corporate bonds purchases, central banks, including the ECB, emphasize the concept of market neutrality as the guiding principle. What it means is that the purchase program should keep relative prices across assets the same, implying that the relative costs of capital across firms should remain the same. Thus, central banks buy bonds in proportion to the amount of bonds outstanding. Doing so they remain neutral also on issues such as firms' climate impacts.

Purchasing risky bonds and funding those purchases with safe debt, the central bank favors more bond-levered and risky firms. On the one hand, the firm's bond spread is decreased by increased

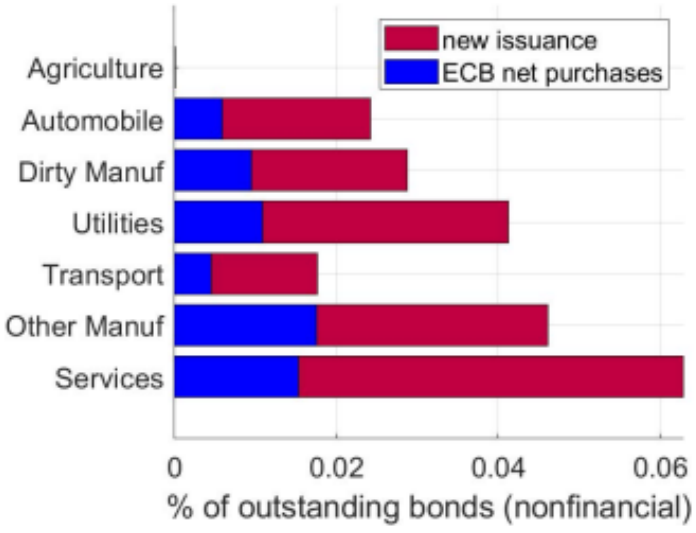
demand and liquidity for its bonds, thus having a larger effect on the firm's overall cost of capital when such firm is more bond-levered. On the other hand, more safe debt in the system lowers all risk premia in the general equilibrium, again benefitting riskier firms more.

The ECB's corporate sector portfolio's bias towards brown sectors is a direct consequence of the bond market's structure and of the simple neutrality formula followed by the ECB to guide its purchases. Firms in the energy and manufacturing sectors, characterized by higher levels of GHG emissions, issue more bonds relative to firms in the service sector, which are responsible for less GHG emissions but tend to finance themselves with more equity and loans.

The difference is driven by the fact that large firms in carbon-intensive industries (automotive, manufacturing, utilities and transportation) tend to have large holdings of fixed, tangible assets, such as machinery and plants, that can be pledged as collateral. Thus, they tend to issue more bonds as a form of financing. Since the ECB aims to be market neutral, its asset purchases are in proportion to the market value of outstanding bonds, creating a bias towards those brown sectors.

This is particularly important when considering that, under the CSPP, the ECB has been an important investor in the market for corporate bonds. Figure 17, based on year-end 2017 data, shows the new issuance of corporate bonds together with the ECB's net purchases, both expressed as a percentage of outstanding non-financial bonds (the financial sector is excluded from the analysis). Between 20 and 40 percent of newly issued bonds of each sector are purchased by the ECB.

Figure 17 – ECB holdings and new bond issuance



Sources: SHS and CSDB (from the ECB)

The current ECB portfolio is thus not market neutral, when defining market neutrality as keeping the relative costs of capital across firms the same. This is to be expected, as every central bank's asset purchase will, even indirectly, favor some firms.

Nevertheless, the central bank can design bond portfolios aimed at lowering emissions, thus taking a climate stance in line with the Paris agreement path. Making dirty firms ineligible for purchases, changing the collateral framework in favor of clean assets, the central bank increases the relative cost of capital of high emitters by increasing their risk premia. [18]

Moreover, the role of government (fiscal) policy also plays an important role. If an optimal carbon tax is in place, an asset purchase program doesn't need to take climate externalities into account and can simply focus on minimizing financial frictions. An optimal (carbon) tax would be one that maximizes social welfare while being subject to a set of economic constraints. [19]

7. Monetary policy in a new environment and interest-rate risk for the green transition

An additional challenge for the ECB's role in maintaining price stability while supporting the green transition comes from recent events, such as the COVID-19 pandemic and Russia's invasion of Ukraine, that stressed supply chains and financial markets.

The last three decades have been characterized by a continuously increased interconnectedness of the global economy, with strong implications for supply and demand.

China's entry into the global economy led to increased global supply of labor, reduced inventory levels and costs. The emergence of new producers in the energy sector (such as the US shale oil and gas) increased the elasticity of global oil and gas supply. Globalization allowed growth to be less strictly tied to swings in domestic demand, as countries could now rotate demand towards the rest of the world when faced with domestic slumps; as an example, during the European sovereign debt crisis, external demand more than doubled as a share of euro area GDP. [20]

These forces, that created the ideal conditions for low and stable inflation, now seem to have disappeared as a consequence of the zero-COVID policies, energy production cuts and Russia's invasion of Ukraine that introduced new supply constraints in the economic system. While some of these constraints are likely to fade over time, as demonstrated by decreasing commodity prices and delivery times as well as lowering shipping costs, there are two key shifts in the new global map.

7.1 The "new normal"

The first one is a shift from efficiency to security in global supply chains. Strategic industries are being re-shored as many industrialized economies are starting to see their past de-industrialization as a vulnerability, with the likely outcome being increased costs and affected production during the adjustment process.

The second shift is from dependence to diversification, especially in the energy sector. The Ukraine war exposed Europe to the costs of over-dependence from a single energy supplier, pressuring governments to look for diversification of the energy supply. This process is expected to have several ramifications in the coming years: first of all, countries will likely have to pay a premium for

some time to attract uncontracted liquified natural gas to replace the Russian one. Moreover, in the medium to long term, investments in renewables are likely to accelerate, boosting both energy supply and aggregate demand.

During the transition process, economies will face uncertain effects on both sides: lower investment in oil and gas, following the green transition, could put upward pressure on fossil fuel prices while demand remains high. At the same time, a negative wealth effect could be triggered while writing off existing carbon-intensive capital, thus lowering aggregate demand.

This is thus an uncertain context, where ensuring price stability becomes more challenging.

While current European inflation remains far too high, having reached double digits and levels never seen since the start of the monetary union, the risk of a recession is increasing, following the strong hawkish ECB's policy stance aimed at withdrawing support for aggregate demand and ensuring that inflation expectations remain anchored to avoid second-round effects. Such policy measures include a drastic increase of policy rates and the stop of net asset purchases. [20]

7.2 Is the current ECB policy stance appropriate?

Higher rates, while needed to curb inflation and bring it back to the 2% target, may negatively affect the green transition, as the effects of interest rate changes are not symmetric across economic sectors. To this regard, some argue that unless greenhouse gas emissions are cut rapidly, economies may be exposed to "climateflation" or "fossilflation" phenomena, that are persistent inflationary pressures associated with more frequent natural disasters and a continued dependency and oil, gas and coal. [17]

Negative effects on the green transition from higher interest rates come from the fact that technical innovations and renewable energies are capital-intensive, being characterized by large upfront costs. This makes them very susceptible to changes in the cost of credit.

In fact, fossil fuel-based power plants have relatively low upfront costs, when compared to wind or solar farms. This makes renewable energies way less competitive in a high-rates environment. For instance, simulations suggest that the LCOE (levelized cost of electricity) of a gas-fired power plant would increase only marginally if discount rates were to double, while the one of off-shore wind would rise by nearly 45%. [17]

There are thus diverging opinions on the current ECB's monetary policy stance, as some are concerned that it may ultimately slow down the decarbonization pace.

Nevertheless, it is the ECB's opinion that failing to arrest the current high inflation in a timely manner would jeopardize the green transition even more fundamentally. In fact, there are several interrelated reasons why tighter financing conditions are the appropriate response to the current challenges.

First of all, high inflation increases uncertainty and distorts relative price signals that are relevant for investment decisions.

The 1970s experience shows how calibrating a policy on the assumption that inflation will decline by itself is not effective. In fact, if not addressed through a strong monetary policy stance, inflation tends to remain uncontrolled, with the risk of resulting into productivity slowdowns.

Financing conditions need to remain restrictive, slowing down aggregate demand and alleviating upward price pressures to return to the 2% target, thus ensuring that long-term inflation expectations remain anchored.

It thus becomes clear that price stability is a precondition for the green transition.

It is also worth noting that, despite the increase in the cost of credit, financing conditions remain favorable from an historical perspective. In fact, investments, and thus the green investments needed for the transition to a carbon-neutral economy, are affected by real long-term interest rates, not nominal and short-term ones. Current measures of long-term real rates (as measured by long-term government bonds) remain low in historical comparison.

Moreover, firms' borrowing cost is a function of (risk-free) interest rates and the risk premium related to the specific company. ECB staff documents a positive relationship between the greenhouse gas emissions of a firm's operations and their credit risk estimates. This means that firms not actively reducing their carbon footprint will face higher risk premia at any given level of risk-free interest rates, resulting in higher borrowing costs. [17]

8. Conclusions

This thesis examined the implications of climate change for the economic and financial systems, showing how the effects of physical and transition risks on households and non-financial corporations transmit to the financial sector, with implications for banks and insurance companies.

Physical risks, meaning extreme weather events, changing precipitation patterns and increased temperatures, jeopardize infrastructure, crop yields and water availability in a non-linear fashion across different geographical areas, potentially increasing resource scarcity and putting upward pressures on prices.

Transition risks, those stemming from the implementation of policies aimed at net-zero emissions, generate different impacts on different economic sectors. Industries that are heavily reliant on fossil fuels, such as mining, agriculture, electricity and gas, will be the most affected by carbon taxes or policies aimed at lowering GHG emissions, due to increased production costs and stranded assets. Conversely, renewable energies and related technologies will benefit the most.

Such risks faced by non-financial corporations transmit to the banking system through the credit and market channels, meaning through the loan and bond portfolios held by banks, with potential deteriorations in the probability of default of such portfolios resulting in capital losses and weaker balance sheets for the banking sector.

This is a first point of interest for the ECB. In fact, in its role of banking supervisor, it must monitor and ensure the soundness of the European banking sector. This is currently done through supervisory stress tests, exercises aimed at assessing the risk profiles and performances of banks under different adverse, but plausible scenarios. In this regard, the ECB economy-wide climate stress test has been the first exercise aimed at understanding the resilience of European firms and banks to climate-related externalities, clearly showing the benefits of an early and orderly transition to a carbon-neutral economy with respect to other adverse scenarios characterized by a late and disorderly transition, or no transition at all.

Physical and transition risks do also affect macroeconomic variables such as GDP, unemployment and inflation, and are thus studied and monitored by central banks worldwide for the fulfillment of their price stability mandates.

To this regard, the ECB implemented changes to its monetary policy framework to account for climate risks. Adjustments to the collateral framework and eligibility criteria for asset purchases

are expected to provide incentives for firms to decarbonize their activities, while preserving the soundness of the central bank's balance sheet by reducing or removing exposures to those sectors that are more likely to be affected by climate risks. This is particularly important when considering that the current ECB's corporate portfolio is tilted towards high-emitting sectors, as a consequence of the market neutrality formula used for asset purchases and the bond market structure. In fact, the guiding principle of (corporate) asset purchases has been to keep relative prices across assets the same, thus buying bonds in proportion of the bonds outstanding. This led to an "overweight" of brown sectors in the ECB's portfolio as dirty industries tend to issue more bonds than cleaner ones, having more tangible assets (such as machinery and plants) that can be pledged as collateral.

Nevertheless, there are different and conflicting views on whether central banks, and thus the ECB, should take an interest in climate change, and if so, whether they are currently doing enough.

Some argue that monetary policy is a weak substitute for fiscal policy, as the latter is far better suited to address climate change through carbon taxes and investment in green technologies. Asking central banks to step in where government officials can't or won't, may also expose central banks to reputational damages and loss of political independence. This is something to consider, especially when accounting for the fact that, although there is ample evidence that some human activities have negative effects on the environment, there is still plenty of uncertainty on what a given level of carbon dioxide in the atmosphere will mean for the climate in the future, and its repercussions on the economy. This shouldn't discourage modelling and forecasting, both from scientists and economists, but should at least suggest caution in building monetary policy around current climate assumptions. Excessive confidence in the current understanding of climate externalities and their effects on the economy may backfire over the long term and hinder credibility through false promises of success. [21]

Many central banks, ECB included, have the secondary objective of supporting the general economic policies of their countries (for the ECB, the European Union). When and if such policies will start to actually consider the fight to climate change a priority, making the necessary investments in green technologies and structuring effective carbon taxes, isn't it that a strict market neutral central bank's approach will already be in line with its secondary mandate?

Still, current consensus considers climate change a financial stability risk and asset prices seem not to reflect the true exposure to physical and transition risks. This allows central banks to tackle climate change under their mandates.

In fact, under this view, the ECB has the responsibility to make the financial institutions it supervises treat these risks as rigorously as any other risk category. Moreover, even tilting its balance sheet's corporate holdings towards issuers with a better climate performance, as long as it doesn't jeopardize price and financial stability, is reasonable, as it allows to preserve the soundness of such balance sheet.

References

[1] Climate Change: Atmospheric Carbon Dioxide | NOAA Climate.gov

[2] Paris Agreement - Status of Ratification | UNFCCC

[3] IPCC — Intergovernmental Panel on Climate Change

[4] Positively green: measuring climate change risks to financial stability (europa.eu)

[5] The green swan - Central banking and financial stability in the age of climate change (bis.org)

[6] Policymakers as policy takers – accounting for climate-related and environmental factors in banking supervision and monetary policy (europa.eu)

[7] The European Climate Law and the European Central Bank (europa.eu)

[8] Climate-related financial disclosures of the Eurosystem's corporate sector holdings for monetary policy purposes (europa.eu)

[9] The evolution of stress-testing in Europe (europa.eu)

[10] What is carbon neutrality and how can it be achieved by 2050? | News | European Parliament (europa.eu)

[11] What makes a bank significant? (europa.eu)

[12] ECB's economy-wide climate stress test (europa.eu)

[13] content (worldbank.org)

[14] ECB takes further steps to incorporate climate change into its monetary policy operations (europa.eu)

[15] Quantitative easing | Bank of England

[16] ECB decides on detailed modalities for reducing asset purchase programme holdings (europa.eu)

[17] Monetary policy tightening and the green transition (europa.eu)

[18] *How_unconventional_is_green_monetary_policy.pdf (stanford.edu)

[19] Microsoft Word - Optimal taxation in theory and practice 060109_final.doc (harvard.edu)

[20] Monetary policy in a new environment (europa.eu)

[21] Don’t Rely on Central Banks to Fight Climate Change | Chicago Booth Review