POLITECNICO DI MILANO

School of Industrial and Information Engineering

Master of Science in Management Engineering

ECB stress test on climate change: state of the art, areas of improvements and focus on a mortgage portfolio

ISP case study

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Contents

List of Figures

1. ABSTRACT

The goal of this document is to examine the impact of climate change on banks' activities, with a deep analysis on how new stress tests will take environmental changes into account, and how the previous methodology adopted by European Central Bank could not be adapted to understand possible consequences coming from extreme weather events.

The first economy-wide climate stress test published by ECB in September 2021 wanted to represent the current situation in Europe, and how it will change under three possible scenarios, characterised by different adoption rate of new eco-friendly technologies and, consequently, different changes in the environmental; this paper is the first tentative to also include climate-related events into stress tests, and it needs to be adapted with new tools that before were not already used, such as a dynamic balance sheet approach that, with its characteristic that gives the possibility to modify the portfolio's exposures, permits to reach more realistic outcomes. This introduction was made in the Single Supervisory Mechanism stress test 2022 published in October 2021, where a dynamic view was adopted to consider transition risks coming from the movement to greener technologies in a time horizon of thirty years, with the aim of capture all possible changes in banks' activities and exposures to the credit market.

Having a look on a mortgage portfolio of the biggest Italian bank, this document wants to analyse in practice how credit risk and capital associate to it will change, and how possible consequences, regarding loss given default and probability of default, significant could be for what concern financial institutions' risk appetite framework and capitalization requirements.

Climate change represents one of the major challenges in the next decades for the banking sector: financial players need to develop new culture and integrate environmental consideration in all steps of their decision-making process, as asked also

by European Central Bank in November 2020, with the “Guide on climate-related and environmental risks. Supervisory expectations relating to risk management and disclosure”, a guideline proposed by authorities in which ECB defined thirteen expectations that banks need to put in place to be ready to face environmental issues.

2. ABSTRACT (ITALIANO)

L'obiettivo di questo documento è di esaminare l'impatto del cambiamento climatico sulla attività delle banche, con una analisi su come i nuovi stress test prenderanno in considerazione i cambiamenti ambientali, e su come le precedenti metodologie adottate dalla Banca Centrale Europea non possano essere utilizzate per individuare le possibili conseguenze derivanti da eventi climatici estremi.

Il primo economy-wide climate stress test pubblicato dalla BCE a settembre 2021 voleva rappresentare la situazione attuale in Europa, e come questa potesse variare prendendo in considerazione tre possibili scenari, caratterizzati da una diversa adozione di tecnologie pulite e, conseguentemente, da diversi cambiamenti ambientali; questo documento è il primo tentativo di includere anche gli eventi legati al cambiamento climatico negli stress test, e dimostrare come questi necessitano di essere adattati con nuovi strumenti che prima non venivano usati, come l'approccio di bilancio dinamico che, grazie alle sue caratteristiche che forniscono la possibilità di modificare le esposizioni del portafoglio, permette di raggiungere un risultato più realistico. Questa introduzione è stata realizzata nel Single Supervisory Mechanism stress test 2022 pubblicato ad ottobre 2021, dove l'approccio dinamico è stato adottato in considerazione dei rischi di transizione derivanti dalla transizione a tecnologie più verdi su un orizzonte di trenta anni, con l'obiettivo di identificare tutte i possibili cambiamenti a livello di attività bancarie ed esposizioni al mercato del credito.

Con uno sguardo al portafoglio di mutui della più grande banca italiana, questo documento vuole analizzare anche da un punto di vista pratico come il rischio di credito ed il capitale ad esso associato cambieranno, e come le possibili conseguenze, collegate alla perdita derivante da default e probabilità di default, possano essere significative per quanto riguarda il profilo di rischio e il livello di capitalizzazione richiesto alle istituzioni finanziarie.

Il cambiamento climatico rappresenta una delle maggiori sfide dei prossimi decenni per il settore bancario: i diversi player finanziari hanno bisogno di sviluppare nuova cultura, integrando le considerazioni ambientali in tutti i passaggi del processo decisionale, come richiesto dalla Banca Centrale Europea nel novembre 2020, con la "Guida sui rischi climatici e ambientali. Aspettative di supervisione relative alla gestione del rischio e alla divulgazione", un documento proposto dalle autorità dove la BCE definiva tredici aspettative che le banche dovranno mettere in pratica per essere pronte ad affrontare i problemi ambientali.

3. EXECUTIVE SUMMARY

Climate change has become one of the most critical issues in the last decades: average global temperature is increasing 0.18 °C per decade, and sea level is rising 1.7 millimetres per year since 1981. The gap between richest and poorest countries is growing, generating dramatic socioeconomical consequences, with a loss coming from extreme weather events closed to $2.6 trillion between 2000 and 2019.

Policy makers have started from the begin of the millennium to adopt new actions, from the Paris Agreement, adopted at global level, with the aim to contain the rise in global average temperature below the threshold of 2 °C above pre-industrial levels, to European Green Deal and "Fit for 55" package, where, with these last two documents, EU countries commit themselves to reduce carbon dioxide emissions of 55% by 2030, and to reach the net zero by 2050. Another milestone made by Europe is represented by the EU Taxonomy, that wants to help policy makers and all the actors in the market to define how and which economic activities could be defined as green, in order to be able to reach the global goals defined at world level.

During 2018 and 2020, two national central banks, respectively the Dutch and the French one, started to develop climate change stress test, understanding how bigger the consequences could be, and trying to predict if domestic banks will be ready to face possible losses coming from environmental issues. Thanks to these initiatives, a new risk culture related to extreme weather events was spread to all financial institutions and European Central Bank published a first paper, in November 2020, where it defined thirteen expectations that banks must put in place to be ready to face future damages coming from environmental issues; this document highlighted both the importance of quantitative and qualitative actions to face climate change, introducing a new risk and management framework, able to capture the consequences of all possible scenarios that will affect real economy and financial markets.

In September 2021 the first economy-wide stress test was published by ECB, where authorities wanted to understand the resilience of both financial institutions and non-financial companies to possible extreme weather events. This paper looked at three different scenarios defined by the Network for Greening the Financial System that analysed the impact of climate change on economy in two dimensions: transition pathway and physical risk. This document represented the first initiative made by central banks to integrate environmental changes into stress test, adopting a top-down approach, able to elaborate data contained in centralised databases to have a first glance of banking system in case of increase of transition and physical risk, defined as the cost associate to move to greener technologies and the consequences of more frequent extreme events. ECB analysed also the exposure of non-financial companies to climate change, having a look to three main categories: median European firms, highly emitting firms, and the most exposed to physical risk companies; with this analysis, European Central Bank wanted to comprehend also the financial stability of banks' counterparties, with the final aim of reveal possible critical situations, stimulating non-financial companies to move to eco-friendly technologies to reach the global goals, and giving the possibility to banks to better comprehend which sectors could have an increase in the capital needed when loans will be issued.

The first economy-wide stress test represented a milestone for a new typology of stress test that in the future will be fundamental to better comprehend the economic situation, but it had a bigger limitation: in fact, all the analysis were made with a static balance sheet assumption, that did not permit to banks to modify their exposures during the period under analysis; this hypothesis could be plausible to use when the timeframe is shorter but, in this case, ECB had a look on a time period of thirty years, and it was not realistic to assume that the portfolio's exposure of each bank will not change in three decades. The next step for a better stress test outcomes will be represent by a dynamic balance sheet approach, introduce in the paper published in October 2021, where financial institutions had the possibility to modify their exposure to transition risk, in

order to make their portfolio more efficient. This introduction, on one hand, give the possibility to develop a deeper analysis of extreme events on financial institutions' exposures, but on the other hand, authorities need to understand if the actions put in place by banks could be plausible or not, to comprehend if financial player should entry or exit from one sector in an easy way, or change their portfolio allocation.

The evidence of the importance of climate-related events' integration into banking activities is shown also in the case study, where a mortgage portfolio affected by flooding risk is analysed; this analysis shows how, if RCP 6.0 and RCP 8.5 scenarios are taken into consideration, compared to a baseline scenario represents by RCP 4.5, in a time horizon of twenty years and looking to an exposure on 85 out of 110 Italian provinces, the probability of default and the loss given default could increase of 25% and 39%, respectively. These results highlight once again how deeper will be the consequences of no-transition to greener activities, and how the stability of financial system is not guarantee.

This work is organised in seven main sections. The first one wants to represent the context and the policy makers' action put in place to prevent global climate change risks, coming from a late adoption of green technology; the second one, instead, analyses the Dutch and the French stress test, in order to understand which was the starting point for ECB publications. The third and the fourth describes the expectations that European Central Bank have, and the first economy-wide stress test, respectively.

Section fifth analyses the SSM stress test 2022 published by ECB, a bottom-up exercise with the final aim to comprehend the situation of each single European bank and its stability; the sixth section has a glance on dynamic balance sheet, how it works and how ECB needs to change its stress test standard, considering a time horizon of thirty years and different reference date for the analysis compared to the usual one, in order to take into account transition and physical risk consequences. The last part wants, instead, analyse a real situation of mortgage portfolio, and all the possible consequences of extreme weather events.

4. INTRODUCTION

Climate change is one of the most influential factors for the future of human being, able to change the collective lifestyle and habits, and it represents one of the major challenges of the upcoming decades for firms, central banks, and supervisors; recent years have been marked by raising public awareness on global warming, and all companies need to analyse their current production and consumption patterns, since the emissions of carbon dioxide (CO_2) are unsustainable and create continue increase in temperature, that have gone up an average 0.18 °C per decade since 1981[1], but they also generate sea level rise, from 1.2 to 1.7 millimetres per year on average[2], and an increase in the probability of weather extremes events.

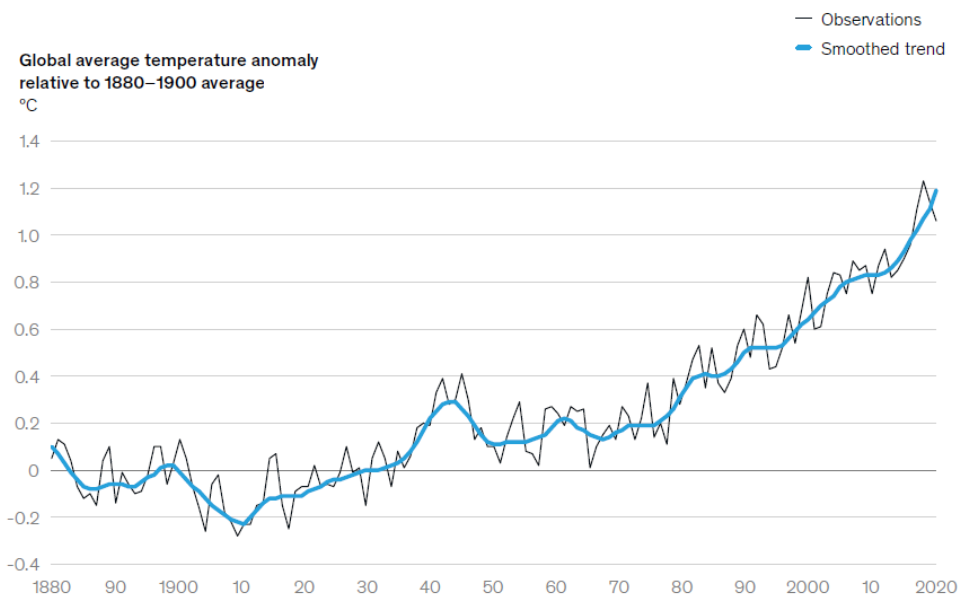

Figure 1: Earth has warmed by roughly 1.1 degrees Celsius since the last 1800s[3]

Many regions across the world are facing substantial increase in physical impacts coming from climate change, that will cause direct effects on six main socioeconomic

[1] https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=Earth's%20temperature%20has%20risen%20by,land%20areas%20were%20record%20warm.

[2] https://ocean.si.edu/through-time/ancient-seas/sea-level-rise#:~:text=Today%2C%20global%20sea%20level%20is,around%203.2%20millimeters%20per%20year.

[3] McKinsey Global Institute (January 2020).

systems: livability, workability, food system, physical assets, infrastructure services, and natural capital. Altogether, between 2000 and 2019, over 475,000 people lost their lives as a direct effect of environmental issues, with a total loss amounted around to $2.56 trillion[4]. Poorest countries are the most expose to climate risks since they rely more on outdoor work: eight out of ten countries most affected by extreme weather events in 2019 coming from low- and middle-income category, and half of them are Least Developed Countries. Nations with lower per capita GDP are not able to take significant actions to prevent such risk, so, in December 2021, at COP 26, the most develop countries signed an agreement to increase the financial contribution to poorest regions with a target of $100 billion per year, useful to face climate change.

Given the urgency of growing impact about environmental issues, many industries are potentially exposed to physical risks, referring to the economic impact on assets and profitability in the long term, and transition risks, coming from the negative consequences that the introduction of climate policies to reduce CO_2 emission could have on high-emitting firms; specific sectors, such as the mining one, will face a radical change in their business model, with a transformation from the current strategy to an eco-friendly approach, in order to reduce carbon dioxide emissions and their impact on environment.

Addressing climate change is a global challenge that needs to match governments and central banks' decisions. While the former have the responsibility to introduce new policies to prevent transition and physical damages that will affect firms' profitability and the stability of financial markets, the latter need to include new tools and models in its policy framework. Central banks can also help to raise awareness on climate risk, with the aim to move financial intermediaries to a forward-looking approach, with the introduction of climate change stress tests, that have the aim to evaluate the return of

[4]Eckstein D., Künzel V., Schäfer L. (January 2021).

assets and risk profile of each single bank over a longer horizon, considering climate-related events.

One major challenge for central banks is to bridge the current gap in the quality and availability of data, with the introduction of new classifications (e.g., EU Taxonomy) that permit to align all players and prevent greenwashing. In this sense, in the last years, the scientific and the financial community publish new studies related possible climate change consequences (e.g., Intergovernmental Panel on Climate Change, 2018) and policy makers put in place several actions and agreements (e.g., Paris Agreement, European Green Deal, "Fit for 55") to align all countries around the world to the same carbon emission target, identify as carbon neutrality in 2050. Thanks to these contributions, all financial institutions and firms are now able to analyse their activities starting from scenarios coming from scientific consensus, with global target, understanding how they could support green transition, and which could be the consequences if climate change's target will not meet.

Addressing these new challenges will require acceleration in adaptation and decarbonization in the following years: each actor, from financial institutions to industrial firms, need to change its risk management, recognizing the obsolesce of past models, with the introduction of a new one that considers climate change as one of the most important variables for decision making.

Changing our collective lifestyle is a tough action problem and all individuals need to take it into consideration. Climate change will not cause only economic disasters but also unpredictable social and political consequences that will influence the future stability at global level. An uncontrolled increase in carbon emissions will generate dramatic outcomes at world level: the increase in extreme natural events will provoke a potential decrease in the collateral value that firms and households provide to banks for loans, generating instability in the credit system; the possible physical damages on infrastructures could be transformed in liquidity problem for companies, that need to repair their assets, or increase their insurance policies, with a reduction of profitability;

consequences of climate change will be faced also at individual level on the worksite, with a reduction of productivity due to extreme temperature, and in the overall lifestyle.

4.1. CARBON EMISSION REPORTING AND DEFINITION

Due to the increase of the importance of climate change year-by-year, companies need to develop a new approach, from an "end-of-pipe" view, aimed at mitigate past activities, to a "proactive" perspective, based on achievement of global objectives, defined by the 17 Sustainable Development Goals (SDGs), that want to guarantee the same possibilities for future generations to satisfy their needs, without relevant changes compared to the current situation. SDGs recognize that ending poverty must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth, tackling climate change and working to preserve environment; Sustainable Development Goals are included in the 2030 Agenda for Sustainable Development adopted by all United Nations Members States in 2015 that has the aim to require to all nations to take climate actions, eradicate poverty and shift into more sustainable development pathways, grouping the main goals in 5 Ps, all interdependent:

- People, including SDGs 1, 3, 4, 5, 10, with the aim of ensuring all human beings can fulfil their potential in dignity and equality.
- Prosperity, that looks at SDGs 6, 7, 8, 9, 11, 12, that wants to guarantee that all people can enjoy prosperous and fulfilling lives, and economic and technological progress occurs in harmony with nature.
- Planet, that include SDGs 13, 14, 15, aiming to protect Earth from degradation, promoting sustainable consumption and production.
- Peace, with SDG 16, to promote inclusive societies.
- Partnership, SDG 17, based on spirit of strengthened global solidarity, focussed on the needs of the poorest and most vulnerable countries.

Figure 2: Sustainable Development Goals adopted by United Nations in 2015

Each company needs to take in place a new sustainability management, with the purpose of connecting each activity with economic and social effects, introducing a risk assessment approach able to define various consequences depending on the decisions that will be made by the firm itself. Each activity should be classified in two dimensions: the severity of possible consequences on environmental, and the probability that climate change problems could happen. Matching these two variables, as shown in Figure 3, companies should take decisions more responsibly, integrating the already used model that analyse the profitability of one decision, with a new one, that has the aim to include also environmental issue that could arise.

Probability

Severity

	Likely	Unlikely	Highly Unlikely
Serious	Intolerable	Significant	Moderate
Moderate	Significant	Moderate	Tolerable
Minor	Moderate	Tolerable	Insignificant

Figure 3: Environmental Management System risk assessment approach

To do it, companies need to shift from a standard business model to a new "Sustainable Business Model", where the variables that are connected to sustainability play a

relevant role in the decision-making process and where the long-term strategies want to maximize the utility function for both firm and society, taking into consideration the environmental issues coming from SDGs. It will be crucial that this new business model will face all risks and opportunities for the sustainable development, and companies need to produce a complete disclosure, not only related to operational issues, but also considering the environmental and climate ones.

To stimulate the transition to greener economies and the transparency of companies, European Union, in 2016, introduced the NFD (Non-Financial Disclosure), a document that firms need to publish if they have more than 500 employees, 20 million of assets or 40 million of revenues, where the main topics are related to environmental, social, personnel related, respect for human rights, corruption and diversity, and where each firm needs to report the main risks associate to each category and how they will manage them in the future.

With this introduction, companies are helped also to change their perspective, where climate change is not only a risk factor, but it could be also a new opportunity: the initial costs that firms will face to be in line with the new regulations and global goals will be more than offset by the advantages that these activities will generate in the following years, with a reduction of future issues connected to extreme events and increase in profitability coming from new and better technologies.

The main parameters that companies have to take under control their performances connected to environment are the greenhouse gas (GHG) emission that can be classified in:

- Scope 1, direct GHG emissions from sources owned or controlled by the company.
- Scope 2, indirect GHG emission created by the generation of electricity or heat needed by the company to produce and sell goods.
- Scope 3, all other indirect emission caused by the entire value chain.

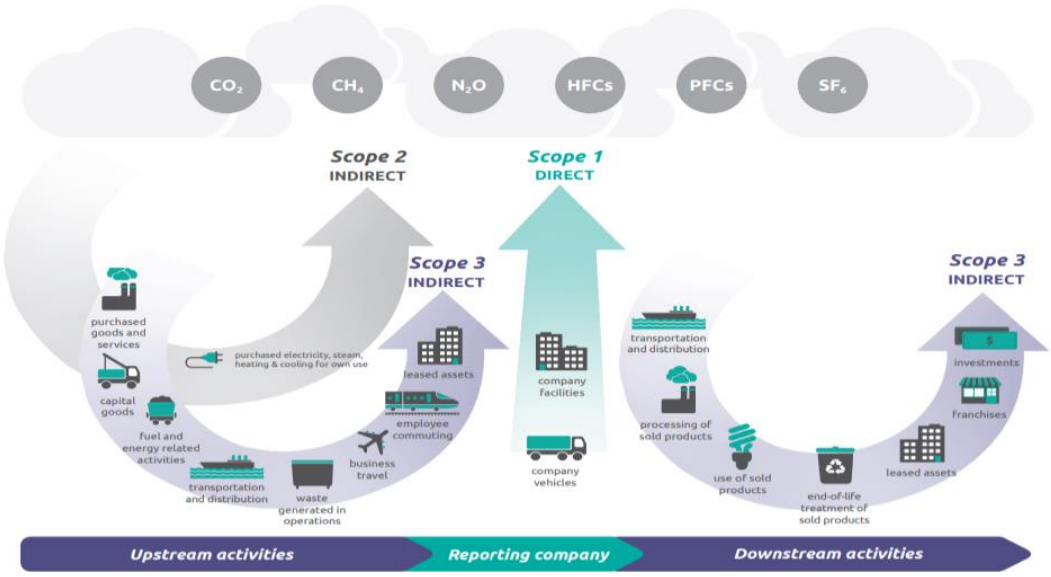

Figure 4: Overview of GHG protocol scopes and emissions across the value chain

The aim is to control both internal and external activities, to create a sustainable supply chain, from the origination to the last mile, in order to reduce, as much as possible, the carbon dioxide emissions; in fact, the problems connected to climate change could not only be related to the single company, but also to all firms with whom it interacts with. A new perspective needs to be adopted by everyone, where the selection of upstream and downstream partners will play a crucial role, with Scope 3 emissions that will be the main point of interest for the risk management.

Despite the importance of a good reporting, authorities are far from the definition of common standards, that will permit to third parties to better understand the position of each company, and to compare one firm to another. This problem could be found also with the Task force on Climate-related Financial Disclosure (TCFD) reporting, where companies that join the initiative need to explain in a clear and comparable way all the information that investors and stakeholders need to better evaluate risks and opportunities connected with climate events. This document has the aim to understand the consequences of possible environmental issues on firms' activities, looking at four thematises: metrics and targets, risk management, strategy, and governance; globally, the four areas are characterised by eleven recommended disclosures that companies need to declare to demonstrate they will be able to face environmental risks and their

business model is sustainable and profitable, also in case of extreme weather events and scenarios; the necessity of common standard of measure is necessary in this typology of disclosure to compare one company's profile to another, to avoid possible misunderstanding coming from different parameters taken into account for the same element of analysis, with the generation of misleading results.

4.2. PARIS AGREEMENT, EUROPEAN GREEN DEAL AND "FIT FOR 55" PACKAGE

At country level, the Paris Agreement represents a milestone for the climate change mitigation, adopted by 195 parties in December 2015, and entered into force in November 2016. Its long-term goal is to contain the increase in global average temperature below the threshold of 2 °C above pre-industrial levels, and to limit this increase to 1.5 °C: in this way, countries commit themselves to an economic and social transformation, with the objective of reducing their greenhouse gas emissions; due to the global importance of the transition, richest countries need also to help poorest ones to develop sustainable economies in order to cooperate to reduce negative climate change at world level.

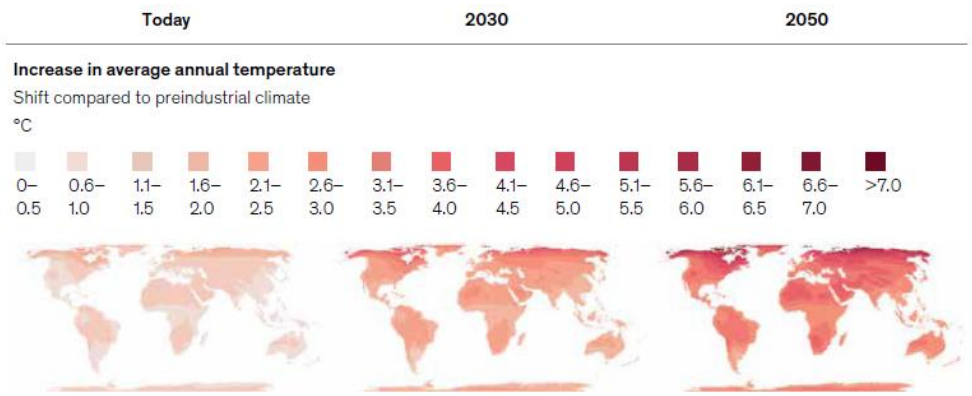

Figure 5: Increase in average annual temperature[5]

[5]McKinsey Global Institute (January 2020).

With the adoption of Paris Agreement, the United Nations Framework Convention on Climate Change (UNFCCC) invited the Intergovernmental Panel on Climate Change (IPCC) to provide, in 2018, a report, known as SR1.5, to assess not only what 1.5 °C increase would generate, but also the different pathways by which the rise of global temperature could be limited. It considers the importance of the achievement of SDGs and shows how, higher will be the adoption of them in companies' culture, lower will be the size of emissions and, consequently, the global warming; every additional 0.5 °C of temperature will cause increase in intensity and frequency of hot extremes events, heavy precipitations, and agricultural droughts, making the situation even more dramatic for the poorest countries. The report identifies five main emission pathways based on temperature trajectory over the 21st century and it examinates three main topics: socio-economic drivers, looking at energy and food demand, near-term climate policies, where a rapid adoption of greener technologies is needed to reach a full decarbonization around mid-century, and the use of bioenergy and carbon dioxide removal (CDR) technologies.

Pathway group	Pathway Class	Pathway Selection Criteria and Description
1.5°C or 1.5°C-consistent**	Below-1.5°C	Pathways limiting peak warming to below 1.5°C during the entire 21st century with 50–66% likelihood*
	1.5°C-low-OS	Pathways limiting median warming to below 1.5°C in 2100 and with a 50–67% probability of temporarily overshooting that level earlier, generally implying less than 0.1°C higher peak warming than Below-1.5°C pathways
	1.5°C-high-OS	Pathways limiting median warming to below 1.5°C in 2100 and with a greater than 67% probability of temporarily overshooting that level earlier, generally implying 0.1–0.4°C higher peak warming than Below-1.5°C pathways
2°C or 2°C-consistent	Lower-2°C	Pathways limiting peak warming to below 2°C during the entire 21st century with greater than 66% likelihood
	Higher-2°C	Pathways assessed to keep peak warming to below 2°C during the entire 21st century with 50–66% likelihood

Figure 6: Classification of pathways[6]

The five scenarios are grouped in two main sections, considering 1.5 °C and 2 °C as cap for the increase in temperature: 1.5 °C-consistent pathways are characterized by a rapid phase out of CO_2 emissions, achieved by broad transformations in the energy,

[6]IPCC (2019).

industrial and transport sectors; in fact, with no or limited overshoot of 1.5 °C, global net carbon emissions decline by 45% from 2010 levels by 2030, reaching net zero around 2050. Instead, for limited global warming below 2 °C, CO_2 are projected to reach the net zero around 2070.

The five Shared Socio-economic Pathways (SSP) can be classified as follow:

- SSP1 Sustainability (Taking the Green Road), that identifies a decline in population (7 billion in 2100), higher income and lower inequality, with less resource intensive consumptions and spread of environmental-friendly technologies.
- SSP2 Middle of the Road, characterized by a medium population growth (9 billion in 2100), with medium income and technological progress, and only gradual reduction in inequalities.
- SSP3 Regional Rivalry (a Rocky Road), that includes high population growth (13 billion in 2100), low income and continued inequalities, with slow rates of technological changes.
- SSP4 Inequality (A Road divided), with similar population of SSP2, medium income but significant inequalities across regions.
- SSP5 Fossil-fuelled Development (Taking the Highway), characterized by decline in population (7 billion in 2100), higher income and lower inequalities, as SSP1, but with resource-intensive production.

European Union was fundamental for the intermediation during the Paris Agreement, proving a strong sensitivity about the topic and electing itself as one of the global leaders in the commitment about climate change mitigation, with a reduction of 24% of CO_2 emission from 1990 to 2018, even if the total emissions of EU countries are only 8% of the global one.

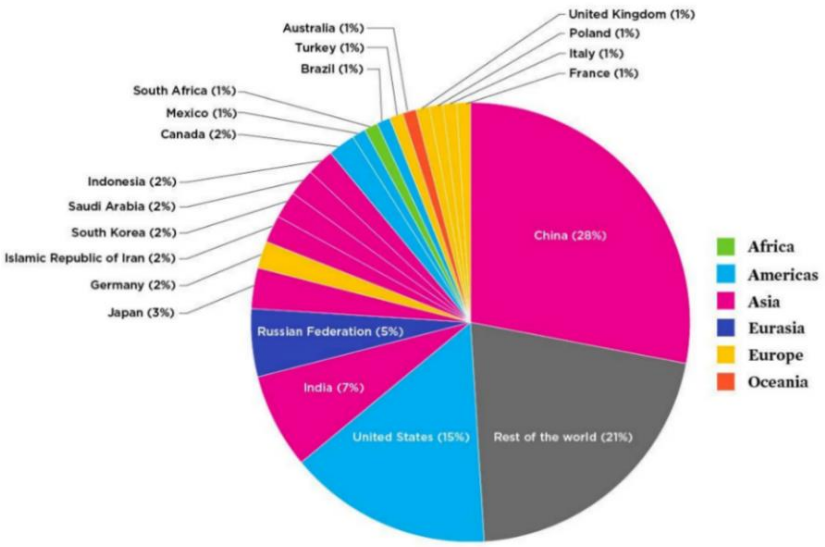

Figure 7: Annual total carbon emission by country[7]

The second milestone to protect environment was the European Green Deal (2019), defined by the president of the European Commission as "man on the moon moment", that aims to meet the net zero in Europe by 2050 introducing carbon taxes to incentivize the highest emitting firms to shift to greener technologies and plans for circular economy, sustainable mobility, and reforestation, with the final goal to favour transition to eco-friendly activities.

In July 2021, to integrate the European Green Deal, the European Commission adopted the "Fit for 55" package, a wide set of policy with the aim to achieve a reduction of carbon dioxide emission of 55% by 2030 compared to 1990 levels, and net zero by 2050. This document consists of a set of inter-connected proposals, which all drive toward green transition by 2030 and beyond, and the main pillars are:

- Update of Emission Trading System[8] (EMS), with the introduction of new sectors (e.g., maritime one from 2023), exclusion of UK emissions since January

[7] https://www.ucsusa.org/resources/each-countrys-share-co2-emissions

[8] Emission trading is a market-based mechanism where a regulator defines a GHG emission gap as maximum threshold for a specific sector of an economy; emission permits are allocated to the entities within the emission trading scheme (ETS). Companies that use less than their permits should sell excess to other participants in the scheme with the final result that low emitting firms will have a gain from the selling of permissions, instead highest emitting firms will face a reduction of their profitability, coming from the purchase of the allowances.

2021, establishment of an Innovation Fund for innovative technologies, and a Modernisation Fund to help countries to renovate their power sector.

- Regulation on land use and forestry, setting an overall EU target for carbon removal by natural sinks, equivalent to 310 million tonnes of CO_2 emissions by 2030.
- Renewable Energy Directive, where the final goal is the produce at least 40% of energy from renewable sources by 2030.
- Revision of Energy Taxation Directive, proposing an alignment between the taxation of energy products with EU energy and climate policies, promoting clean technologies.

The EU "Fit for 55" package also provide the introduction of a Carbon Border Adjustment Mechanism (CBAM), that will represent an addiction tax on carbon connected to products that will be imported from extra-EU countries, with the final aim of taking into account in the price that these products were realised with lower environmental standards. Since 2023, CBAM applies only to five sectors (e.g., iron and steel, aluminium, cement, fertilizers, and electricity) but, from 2026, it comes into force in full. With the adoption of this mechanism, importers would have to register with a regulator and buy carbon allowance ("CBAM certificates") to cover the emissions embedded in their products, guarantee a major attention of Scope 3 emissions, due to firms need to also analyse sustainability of their suppliers if they want to maintain the same level of profitability and not pay an addiction tax.

4.3. EU TAXONOMY

The EU Taxonomy (July 2020) was the first elective European green classification system useful to identify the economic activities that make a substantial contribution to environmental objectives, with the final goal of encouraging transition toward

sustainability; companies can reliably use this tool to plan their climate and environmental transition and raise finance, protecting investors against greenwashing and accelerate the financing of those projects that are already sustainable in order to meet the objectives of European Green Deal.

The Taxonomy Regulation identifies six EU environmental goals:

- Climate change mitigation.
- Climate change adaptation.
- Sustainable use and protection of water and marine resources.
- Transition to circular economy.
- Pollution prevention and control.
- Protection and restoration of biodiversity and ecosystems.

An activity, to be align to the Taxonomy, must make a substantial contribution to at least one environmental objective, doing no significant harm to any other ones, complying with minimum social safeguards and technical screening criteria; these criteria are specific for each economic activity, ensuring substantial contribution[9] to the environmental goal.

EU Taxonomy Regulation sets mandatory requirements on disclosure, with the aim of proving transparency on environmental performances: those companies that fall under the scope of the Non-Financial Reporting Directive (NFRD)[10] will have to reveal how their activities will meet the criteria set by EU Taxonomy. This aspect will play a crucial role in the future for the financial system: banks might have an incentive to finance Taxonomy-aligned economic activities, helping companies to make investments against transition and physical risks, knowing how these resources will be

[9]Substantial contribution: the economic activity either has a substantial positive environmental impact or substantially reduces negative impacts on the environmental.
[10]NFRD's aim is to deliver a comprehensive corporate reporting framework with qualitative and quantitative information to facilitate the assessment of companies' sustainable impacts and risks.

used, and firms will be motivated to reach a level of environmental performance that financial markets recognise as green.

The Taxonomy helps also to identify which are the bonds' amount that are used to finance activities in line with the classification. Green bonds are a source of funding for those activities that are directly connected to environmental investments; to identify a bond as "green", it must satisfy four principles, defined by the Green Bond Principles (GBP):

- Use of proceeds, for which purpose the issuer will use the capital (e.g., renewable energy, pollution prevention and control, clean transportation, green buildings, climate change adaptation).
- Process for project evaluation and selection, where the company needs to specify which process is used to select activities to finance.
- Management of proceeds, how firm manages the capital.
- Reporting, where the issuer needs to publish a report in which it explains how it uses these amounts.

Sustainable-linked bonds are instead a source of funding where the coupon depends on sustainable performances of the company: if the firm will not meet its target, the interest for the bond will increase, to compensate company's failure in reaching its environmental goals.

The Sustainable-Linked Bond Principles (SLBP) have five components:

- Selection of KPIs, that should be material to the issuer's core sustainability and business strategy, addressing relevant ESG[11] challenges, measurable or quantifiable on methodological basis.
- Calibration of sustainable performance targets (SPTs), that must be set in good faith and the issuer should disclose strategic information that may decisively impact on the achievement of SPTs.

[11]Environmental, social and governance.

- Bond characteristics, such as the variations of the coupon.
- Reporting, where issuers need to publish up-to-date information about the performances selected as KPI.
- Verification, made by independent and external advisor to check firm's performance.

During the end of 2021, there was the proposal of introduction of fossil gas and nuclear's activities in the taxonomy regulation; this implementation is in contrast with the first publication of the Delegated Act, where nuclear has been excluded due to safe disposal of nuclear waste, and gas has not been considered for carbon footprint. Nowadays, however, in absence of other economically alternatives, the European Commission has recognised these activities as green, and they are considered a good contribution to accelerate the transition to a net zero economy.

Nuclear activities, to be qualified as sustainable, must be able to ensure the presence of disposal plans and funds able to cause no significant harm to the environment, permitting to collect all the nuclear waste that will not spread, and the EU text defines 2045 as the final term to get the construction permit for the installations of new nuclear plants.

Natural gas, instead, will be classified as green only for a limited time span, and providing certain criteria, such as a carbon dioxide emission level of 270g of CO_2 per kilowatt generated; like nuclear activities, also in this case the European Union identifies as 2030 the deadline for the gas facilities' construction to support the green transition and the replacement of more pollution fossil fuel plants.

In this context, the view of the European countries is different from one actor to another: French sustain nuclear activities, considering them as green, due to the non-generation of carbon dioxide emissions, with the only problem connected to radioactive wastes; in the contrast, Germany do not consider nuclear as green, but it looks at natural gas as a good starting point to remove the more polluting fossil fuels activities. A third

group contemplates nuclear and natural gas as not sustainable, and they reject the ideas to consider these two alternatives as green investment, such as the renewable activities.

5. WHERE WE ARE: PAST CLIMATE CHANGE TEST

Since financial crisis, stress tests became crucial to monitor banks' stability and resilience in specific conditions: climate change's problems have been started to be more and more relevant in the recent years and economy-wide stress testing has become a powerful tool to capture the consequences of systemic risks. Comparing climate change with the subprime crises, it should be possible to understand how dramatic it would be, with an expected loss in global GDP equal to 10%, compared to the reduction of 4.3% that there was during the 2008 financial crisis[12]. This difference, that shows how the impact will be double, should be found in the geographic areas under analysis: climate change will affect all countries around the world with dramatic consequences especially for those countries that rely on primary activities; instead, the 2008 crisis started in US, with the spread also in the other countries, but with lower effects. For this reason, it is crucial that all players in all the markets, from the financial companies to the non-financial ones, from the richest to the poorest, will start to shift their activities to an eco-friendly approach, able to reduce possible consequences coming from extreme weather events that will generate dramatic outcomes for all the actors. Despite the scientific consensus about climate change, the exact timing and the magnitude are unknown; national central banks understood the importance of energy-transition stress test and they began to run it in order to perceive the possible impacts of a late passage to clearer activities.

Scientific community defined what is called "carbon budget" as the quantity of CO_2 that economic activities could produce to be in align and to achieve the Paris Agreement's target. This budget is estimated to be 420 gigatonnes of CO_2 for a two-thirds change of limiting warming to 1.5 °C, and of about 580 $GtCO_2$ for an even glance[13]: since average carbon emissions during 2020 are equal to 36-38 gigatonnes of

[12] https://www.federalreservehistory.org/essays/great-recession-of-200709
[13] IPCC (2019).

CO_2, in the former case the carbon budget will end in eleven years, instead in the latter the remaining time will be fifteen years. The trend of CO_2 emissions is increasing, as shown in Figure 8, with a small reduction in the last years due to the Covid-19 situation, characterised by several lockdowns around the world that had stopped firms' activities; 2021 was one of the fifth hottest year, mainly due to rise of carbon dioxide, that reach its highest average, reaching 414 parts per million, and methane in the atmosphere, with a consequent increase in natural disasters, with an year global average temperature in Europe of 1.1-1.2 °C above the pre-industrial average. In this situation, both companies, governments and regulators need to analyse these data and change their behaviours if they want to be aligned with Paris Agreement's target.

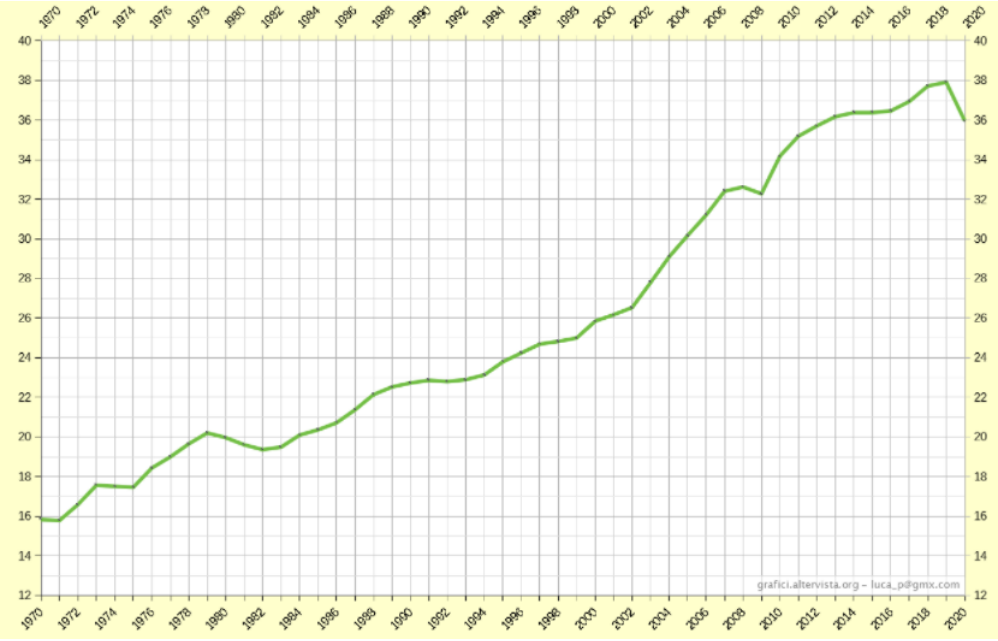

Figure 8: Global carbon emission in gigatonnes[14]

It is important that all banks understand that analysing climate change's effects will be not only feasible but also extremely useful to comprehend their stability and future problems in all possible scenarios; it is crucial to develop a common base of knowledge and criteria that all institutions can use to analyse the situation and to obtain results that

[14] https://grafici.altervista.org/emissioni-di-co2-pro-capite-e-totali-in-italia-e-altri-paesi/

can be compared, allowing them to realize the interactions between transition and physical risks.

Stress testing for climate change is different and more complicated compared to existing macro stress test, mainly due to:

- Lack of historical data, that creates a new challenge for regulators about modelling the right interactions between climate change, macroeconomy and financial sector, that are important inputs to develop coherent and plausible scenarios.
- Time horizon, in fact, for macroeconomic stress testing, ECB takes under analysis three years, instead, due to the nature of climate change, the time horizon is expanded from thirty to fifty years[15], making the assumptions more difficult, with a complexity in understanding which assets will be most affected by climate-related risks and how bigger could be these impacts.
- Credit losses, related to creditworthiness of counterparties, that become challenging to estimate with a longer time horizon, with no data about near-term for back-testing. Banks are facing pressure from regulators to integrate risks related to climate change in their risk appetite framework: in 2020 alone, the physical risks cause $220 billion in economic damage but, over the long run, transition risks could cost trillions of dollars to banks[16], affecting the stability of financial system.
- Macroeconomic stress tests assume no action about hedging or reduce exposure, that could be true in case of three years under analysis, but it is not credible in case of climate change stress test, making the static bank balance sheet assumption implausible. The next step would be to include climate risk into the rating and underwriting process, creating borrower-specific climate risk scores,

[15]ECB, in its "Climate risk stress test. SSM stress test 2022" (October 2021), defines three different horizons (2030, 2040, and 2050) to analyse transition risk's scenarios.
[16]https://www2.deloitte.com/us/en/insights/industry/financial-services/climate-change-credit-risk-management.html

scrutinize factors including client's decarbonization progress and availability of renewable energy technologies to power operations.

- Uncertainty about actions coming from other market participants and policy makers.

The current situation shows how the field of analysis about climate change opaque is, where banks are required to model the impact of the scenarios on expected losses for corporates, households, and government exposures without sufficient data to effectively assess the relationship between climate risks and credit losses, for what concern credit risk, and the possible drop in equity price for high-emitting firms, looking market risk. Counterparty-level projections require a large amount of information about future actions of the borrower to face climate risk, that could be taken from companies' NFD, but such information are typically available only for large counterparties; additionally, financial institutions need to make assumptions about impacts on property values coming from physical and transition risks, generating a reduction in the collateral value, making the stress testing time-consuming and more complicated for companies that have physical assets in many geographical locations, with different consequences coming from climate-related events.

5.1. 2018: DE NEDERLANDSCHE BANK

In 2018, De Nederlandsche Bank (DNB) became one of the first central bank to run the energy-transition risk stress test; DNB collected data on bond and equity holdings at individual securities' level of Dutch banks, insurers and pension funds that gave the permission to build a detailed picture of their exposure in all sectors. Secondly, to understand the impact of climate change, DNB calculated a transition risk vulnerability factor for each industry in the economy with different assumptions, based on CO_2 emissions and, to model the different interactions, the process was divided in two steps:

the first one, looking at the connections between the environmental policies and the macroeconomy, and the second one, analysing the impacts of these effects on the financial system.

The stress test was conducted by hypothesized four severe but realistic energy transition scenarios that came from the interaction of two risk factors: government policies and technological developments.

The main hypothesis of the test were:

- Drop in consumers and investors' confidence in case energy transition will be postponed and technological breakthroughs were absent.
- Look at a time frame of five years, to ensure that stress test's outcome will be relevant for all financial institutions.
- Physical risks coming from climate change (e.g., floods, tornados, earthquakes) were not considered in order to connect the potential losses only to the energy transition risks.

Each scenario was first translated into an impact at macroeconomic level and then disaggregated at meso level, to understand the consequences on the fifty-six industries, based on carbon emissions, and the financial impacts.

To translate each scenario into a macroeconomic impact, DNB used NiGEM, a multi-country macroeconomic model, that allowed to take into consideration the consequences of energy transition risks at global level, considering also that Dutch financial institutions are more exposed to international companies compared to national ones.

The stress test discriminated between exposures to fifty-six industries, based on each sector's vulnerability to carbon emissions emitted to produce final goods and services. It took also into account the so-called "embodied CO_2 emission", the emission of each industry plus the emission of the suppliers.

The four scenarios under analysis were:

- Technology shock, due to technological breakthroughs, renewable energy's share in the energy mix will double.
- Double shock, carbon price will rise to 100 $/ton due to policy measures and the renewable energy's share in the energy mix will double.
- Confidence shock, corporation and household will postpone investments due to uncertainty about both technological breakthroughs and policy measures.
- Policy shock, carbon price will rise to 100 $/ton due to policy measures.

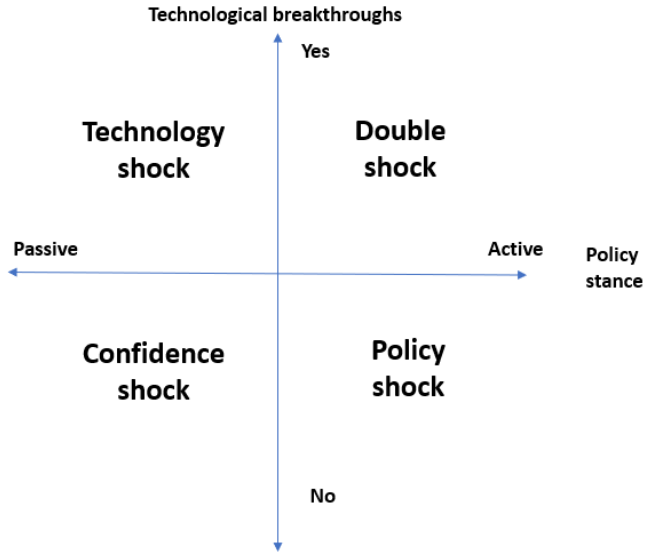

Figure 9: Four disruptive energy transition scenarios

Since Dutch financial institutions play a relevant role worldwide, both technological and political aspects must be considered at global level; scenarios were defined in such a way they can materialize in the short-term, meaning an immediate relevance for financial players and decision makers.

The stress test suggested financial institutions can mitigate their vulnerability including energy transition risks in their risk management, mapping their exposures to industries that represent the most exposure to climate change's consequences. Banks should change their investment policy to finance firms that are active involved in the energy transition in order to decrease the probability of a disruptive scenario: the stress test

suggested that a disruptive energy transition can already affect Dutch financial institutions in the short term and, moreover, these effects and losses for financial players will not be confined to exposures to carbon-intensive industries, but the consequences will be spread in all industries and in the global financial system.

This stress test represents only a first step toward the implementation of a more accurate framework since the outcome depends crucially on the assumptions. A new methodology needs to expand the scenario analysis, taking into consideration also physical risks and not only the transition ones, that should be the most relevant for the stability of banking sector, extending the time horizon from five years to a more relevant time frame, that gives the possibility to include all possible consequences in the long-term coming from environmental changes, analysing also the effects of energy transition risks for household, and taking into consideration the IPCC five scenario defined in the SR1.5 report.

5.2. 2020: BANQUE DE FRANCE

The second relevant climate change stress test that must be taken into consideration is the one conducted by Autorité de Contrôle Prudentiel et de Résolution (ACPR) and Banque de France (BdF) during the 2020; they considered the effects of transitional and physical risks on credit risk, market risk and sovereign risk for nine banks and fifteen insurer groups over the next thirty years, setting macroeconomic and financial variables projections over the long term, in five-year intervals, in order to reflect possible future trends. It was also an innovative kind of analysis, with a first hypothesis of dynamic balance sheet: this introduction permits to analyse more realistic scenarios where banks and insurers can invest in and out of economic sectors based on their climate risk-reward considerations, providing results and information on the strategies of financial institutions.

The transition risk's scenarios included a baseline scenario, that looked at an orderly transition, and two disorderly ones; each of these scenarios combined an analysis on two elements: trajectory of carbon tax and total productivity levels of factors.

The baseline scenario corresponded to a situation in which France will be able to reach the commitments made under the Paris Agreement: it is the most favourable situation, although it included a significant increase in the price of carbon.

The first adverse disorderly transition scenario was based on late transition: companies are not able to reduce GHG emission by 2030 and more proactive measures are needed. It was based on the assumptions that sequestration technologies will be less efficient than expected and the carbon's price will increase from 14 $/ton of CO_2 in 2030 to 704 $/ton in 2050, in order to meet carbon neutrality target in 2050.

The second adverse disorderly scenario, also called "sudden transition" scenario, combined a sharp increase in the price of carbon, 917 $/ton of CO_2 in 2050, with less efficiency for what concerned renewable-energy technologies, implying a higher energy prices and additional investments.

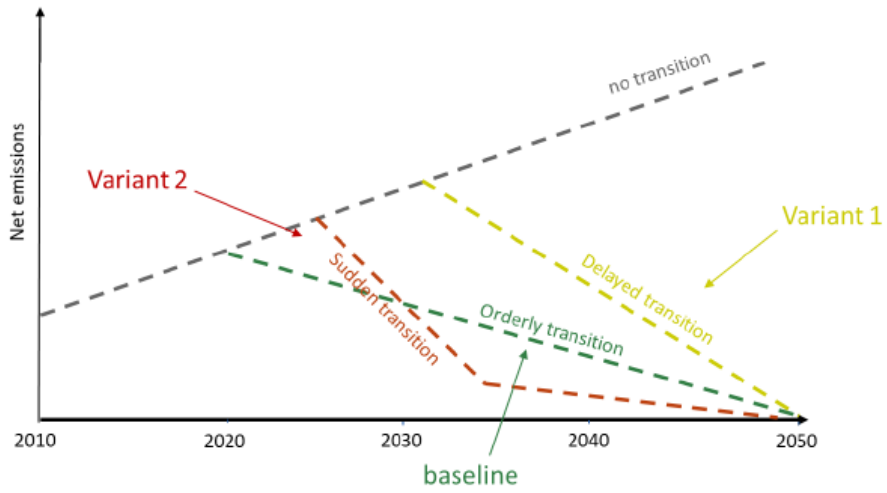

Figure 10: Transition and physical risk scenarios[17]

[17]ACPR and Banque de France (2021).

The relevant point introduced by ACPR and BdF was the dynamic balance sheet assumption: banks and insurers needed to project their credit risk in the various scenarios provided, to understand their capital and exposure consistency, permitting them to reallocate their corporate credit portfolio across different economic sectors, looking at climate change problems. Dynamic balance sheet hypothesis also revealed the diversity between banks' strategy taken under analysis: six financial institutions had a high exposure to the manufacture of coke and refined petroleum products sectors, and they must change their credit exposures between 2025 and 2050 according to the sudden transition scenario, realigning their credit structure to meet the carbon neutrality; by contrast, two other banks had no relevant exposure to these activities, so they could continue to develop their strategy running a sector-by-sector analysis, to have a clearer perception of the economy as a whole; lastly, two institutions have implemented an exit policy from highest emitting sectors, in line with their public commitments.

In general, two types of strategies could be identified:

- Some institutions chose to finance the global economy, aligning their credit portfolio with the sectoral structure of the economy; this decision could come from the difficulty for some financial player to decide on strategic management actions with a thirty years' time horizon, with problems connected to projection coming from new stress test methodology.
- Other banks conduct a sector-by-sector analysis to have more details for the allocation of their portfolio, in which the choice may depends on existence of public commitments, willingness to support key sectors for the transition, pressure from civil society to reduce certain sectoral exposures or analyses on sectoral dynamic up to 2050 to improve portfolio allocation and bank's stability.

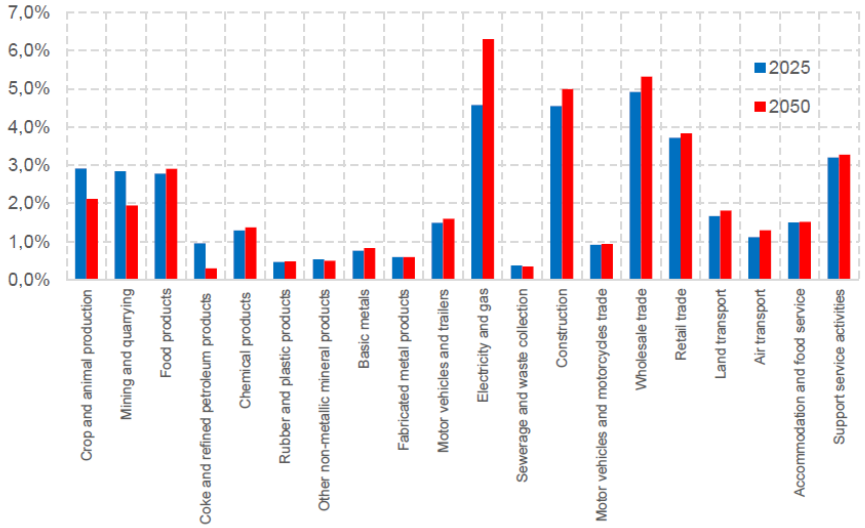

Figure 11: Sectoral structure of credit exposures[18]

For what concerned the cost of risk, it will be higher in the adverse scenarios compared to the baseline one, with a huge increase in 2025, when the price of carbon will rise significantly: this will be reflected by a decrease in GDP growth, with significant impacts on sectors where the carbon's price is crucial, such as mining or manufacture of coal.

Looking at market risk, it was divided into two-categories: fair value revaluation of the trading book, coming from a reduction of stocks' price induced by adverse transition scenarios, and impacts of market shock on the counterparty risk for the most emitting sectors. Analysing the first component, the stress test considered equity, corporate and sovereign credit spread and oil-related position: the instantaneous impact coming from a sudden transition will reach 160 million euros on the top six banking institutions, instead for a delayed transition it will be 69.6 million euros. The second component, the counterparty risk analysis, had a range for the six largest banks between 190 million euros and 145 million euros, respectively in the sudden and delayed transition scenarios. The market shocks used for this exercise were significant but applied to only a small portion of banks' portfolio, analysing the impact only on equity in sensitive sectors and corporate credit spread in the same sectors; in addition, the results were

[18]ACPR and Banque de France (2021).

also influenced by short position that financial institutions had at the cut-off date studied that permitted to offset the adverse impact of shocks.

Like credit risk, the most vulnerable sectors were the ones connected to mining and manufacture of coke; with this analysis, banks could manage better their tactical and strategical positions in their trading book, looking not only risk-reward strategies but also possible climate change issues that can influence exposures that will be hold for a short-term.

The other aspect under analysis was the physical risk assessment, another improvement compared to the Dutch stress test, that was assessed on the basis of Intergovernmental Panel on Climate Change's "RCP 8.5" scenario, which corresponds to a temperature increase comprised between 1.4 °C and 2.6 °C in 2050: banks needed to understand their proportion of exposure at risk to companies that have a geographical location of their properties or value chain that could be affected by extreme climate events, and financial institutions need also to indicate the magnitude of the impacts both for physical risks and changes in insurance policies on credit risk parameters.

If portfolios were secured by immovable properties, in case of extreme weather events, which could affect the value of real estate, the credit risk will be influenced with a decrease of collateral value and a consequent increase in the loss given default. Such events could also have an impact on businesses, leading to a lower turnover and to a decrease in the value added for counterparties at risk, with an increase in the probability of default.

A first challenge for banks will be to identify portfolio's exposures sensitivity to physical risk in case of immovable properties: financial institutions have at their disposal information concerning the location of the buildings, but these are not matched with the risk management system at the consolidated level. The second stage will be to assess the impacts in terms of credit risk: banks need to study past natural disasters

occurrences in order to understand how them influence collateral value, to gain a better understanding of the connection between physical and credit risk.

The pilot test revealed a moderate exposure of French banks and insurers to climate risk, since half of the exposures were located in France, where firms are less affected by physical risks' problems. Despite of that, this exercise achieved its objectives: financial institutions understood the importance of diversification between sectors based on carbon emissions; they raised their awareness about climate risk and how it will be relevant and crucial in the following years; financial players also understood their current exposure and now they are able to mitigate possible risks, integrating climate risks into their financial risk assessment process.

Compared to the Dutch stress test, the French one introduce the consideration of possible impacts of physical risks, understanding how a first necessary step for banks is to integrate the geographical locations of their exposures into their information systems, in order to understand not only the sector exposure but also the geographic vulnerabilities of each immovable property, necessary to better forecast possible damage coming from environmental issues; then, Banque de France extended the time horizon to thirty years, in order to capture all possible effects of climate change, and not only the ones connected to the short term. Another difference compare to the De Nederlandsche Bank's test is the consideration of retail exposure in the credit risk analysis: looking at the difference in the cost of risk between the sudden transition and the orderly one scenarios by 2050, the retail portfolio in the former scenario is only 0.5% riskier compared to the baseline; instead, if the corporate portfolio is taken in place, the difference is equal to 11.6%, highlighting how firms' behaviours represent the most significant variable to take under consideration for future banks credit policies.

6. ECB SUPERVISORY EXPECTATIONS RELATED TO CLIMATE CHANGE RISK MANAGEMENT

In their credit and market risk management, banks are expected to consider climate-related and environmental (C&E) risks at all relevant stages of the credit-granting process and to monitor every risk connected to their positions in the portfolio. For this purpose, European Central Bank published in November 2020 the "Guide on climate-related and environmental risks. Supervisory expectations relating to risk management and disclosure" where it defined thirteen expectations and guidelines for each single bank that must be adopted in order to be ready to face climate risks.

These expectations could be grouped in four clusters:

- Business models and strategies, where banks are expected to implement an internal governance process to assess forward-looking impacts of climate factors on banks' activities.
- Governance and risk appetite, where financial institutions need to develop a robust internal process to identify, manage, monitor, and report the environmental risks they are exposed to.
- Risk management, providing detailed guidance on integrating climate-related and environmental risks into credit, operational, market and liquidity risk management, as well as into the ICAAP overall.
- Disclosure policies and procedures, where ECB expects banks publish meaningful information regarding their activities and climate change issues they are exposed to.

6.1. BUSINESS MODELS AND STRATEGIES

The first cluster considers the supervisory expectations relating to business models and strategies, and it is composed by two recommendations:

- Expectation 1, Business environment: "Institutions are expected to understand the impact of climate-related and environmental risks on the business environment in which they operate, in the short, medium and long term, in order to be able to make informed strategic and business decisions". When scanning their business environment, banks are expected to identify all risks arising from climate change related to geographic areas, key sectors, and products they are active in or are considering becoming active in, adopting a granular approach to map these impacts on their business environment.
- Expectation 2, Business strategy: "When determining and implementing their business strategy, institutions are expected to integrate climate-related and environmental risks that impact their business environment in the short, medium and long term". Financial institutions need to take into account any material factor that can be related to their long-term solvency, using stress scenario analyses, and adopting key performance indicators (KPIs) that are cascaded down to individual business lines and portfolio. A short-to-medium assessment is expected to include an analysis looking at the current business planning horizon (from three to five years); instead, a longer-term assessment is based on more than five years, looking at the resilience of the current business model against a range of possible scenarios, coming from climate-related and environmental risks.

These fist two expectations highlight how much the financial sector needs to change its usual activity: ECB realizes the significant magnitude that climate change will have on stability and future strategy of each bank and identifies the importance of moving from the traditional business model to a new one, more connected to sustainability and

climate change. Financial institutions need to develop new KPIs that could represent early worried signals for the stability of portfolio and integrate them into the current risk management framework, in order to be able to prevent possible huge losses coming from a new category of risk (e.g., environmental one) that in the past was not taken into consideration as much as it will be needed to be consider today.

6.2. GOVERNANCE AND RISK APPETITE

The second cluster is related to governance and risk appetite, and it goes from expectation three to expectation six:

- Expectation 3, Management body: "The management body is expected to consider climate-related and environmental risks when developing the institution overall's business strategy, business objectives and risk management framework and to exercise effective oversight of climate-related and environmental risks". Given the relevance of these risks, the management body needs to identify and allocate roles and responsibilities to its members to take under control climate change's consequences, considering knowledges, skills, and experiences.
- Expectation 4, Risk appetite: "Institutions are expected to explicitly include climate-related and environmental risks in their risk appetite framework (RAF)". It must consider all the material risks to which institutions are exposed, forward-looking, in line with the strategic planning horizon set out in the business strategy and that is reviewed regularly, setting limits on lending to sectors and geographic areas that are highly exposed to climate change's risks. Banks need to have a risk management framework that ensures how face possible environmental issues, together with an appropriate follow-up procedure. Regarding climate-related risks, institutions are expected to develop metrics that

take into account how different paths of temperature and greenhouse gas emissions may accentuate existing risks, to understand how much capital will be needed.

- Expectation 5, Organisational structure: "Institutions are expected to assign responsibility for the management of climate-related and environmental risks within the organisational structure in accordance with the three lines of deference model". Institutions must have a transparent and documented decision-making process with a clear allocation of responsibility within their internal control framework, including their business lines, internal units, and internal control functions; moreover, internal audit function is expected to consider in its reviews the extent to which the institution is equipped to manage climate-related risks.
- Expectation 6, Reporting: "For the purposes of internal reporting, institutions are expected to report aggregated risk data that reflect their exposures to climate-related and environmental risks with a view to enabling the management body and relevant sub-committees to make informed decisions". ECB expects institutions to integrate climate risks into their data reporting frameworks with a view to informing decision-making at management level, permitting an understandable and timely identification and measurement of risks.

The second cluster shows how the integration of climate-related decisions starts from the top line management; each bank needs to identify specific figures with the aim of consider each possible environmental issue when a new position in the portfolio will be opened. Due to the increase of climate change's relevance, the management body needs to identify employees with high knowledge in eco-friendly approaches, in order to assign them decision making roles that will be more and more important during the years, especially if climate change worst case scenario will happen.

6.3. RISK MANAGEMENT

The cluster with the highest number of expectations is the third one, related to risk management:

- Expectation 7, Risk management framework: "Institutions are expected to incorporate climate-related and environmental risks' drivers of existing risk categories into their risk management framework, with a view to managing, monitoring, and mitigating these over a sufficiently long-term horizon, and to review their arrangements on a regular basis. Institutions are expected to identify and quantify these risks within their overall process of ensuring capital adequacy". Banks need to have a comprehensive analysis of the ways in which climate risks drive the different areas, including credit, operational, liquidity and market risks and any other material risk for capital under different scenarios, in particular looking at energy transition.
- Expectation 8, Credit risk management: "In their credit risk management, institutions are expected to consider climate-related and environmental risks at all relevant stages of the credit-granting process and to monitor the risks in their portfolios". Financial institutions are expected to define appropriate general risk indicators or ratings for their counterparties that consider climate problems; when critical exposures appear, such risks must be highlighted and considered under different scenarios with the aim of ensuring the ability to mitigate them. Institutions are expected also to understand how the collaterals' value will change in case of climate and environmental risks, including these considerations both in the process for establishing the value of collaterals and into the review process prescribed by the applicable regulations.
- Expectation 9, Operational risk management: "Institutions are expected to consider how climate-related and environmental events could have an adverse impact of business continuity and the extent to which the nature of their activities

could increase reputational and/or liability risks". Banks are expected to assess the impact of physical risks on their operations, including the ability to quickly recover their capacity to continue providing services, and also the increase risk of a negative financial impact arising from future reputational damages and litigations.

- Expectation 10, Market risk management: "Institutions are expected to monitor on an ongoing basis the effect of climate-related and environmental factors on their current market risk position and future investments, and to develop stress tests that incorporate climate-related and environmental risks". Financial institutions need to take into consideration that climate change could lead to potential shifts in supply and demand for financial instruments, products, and services, with a consequent impact on their values. In line with the nature of the ICAAP perspective, institutions are expected to assess risks arising from debt, equity, and equity-related financial instruments in their trading book, as well as foreign exchange positions and commodities risk positions assigned to both the trading and banking book.
- Expectation 11, Scenario analysis and stress testing: "Institutions with material climate-related and environmental risks are expected to evaluate the appropriateness of their stress testing, with a view to incorporating them into their baseline and adverse scenarios". Banks must conduct a tailored and in-depth review of their vulnerabilities through stress testing, looking at all material risks that may deplete internal capital or impact regulatory capital ratios.
- Expectation 12, Liquidity risk management: "Institutions are expected to assess whether material climate-related and environment risks could cause net cash outflows or depletion of liquidity buffers and, if so, incorporate these factors into their liquidity risk management and liquidity buffer calibration". Climate change risks need to be considered also in the ILAAP analysis, conducting it in a forward-looking manner, assuming both business-as-usual and stressed conditions, with a focus on key vulnerabilities. Consequently, banks are

expected to assess whether climate-related and environmental risks could have a material impact on net cash outflows or liquidity buffers.

This cluster is the most material one, in which ECB wants a full integration of climate change consequences in all the risk assessment process, starting from credit, going to operational, market and liquidity risk. Banks need to change their risk management framework, introducing new variables that permit to control the future impacts of environmental issues. Central Bank, with expectation eleven, also highlight the importance of stress test: financial institutions need to develop an internal model based on scenarios function of environmental changes, considering the IPCC ones, or developing their own sketches.

6.4. DISCLOSURE POLICIES AND PROCEDURES

Expectation 13 is the only one connected to Disclosure policies and procedures: “For the purpose of their regulatory disclosures, institutions are expected to publish meaningful information and key metrics on climate-related and environmental risks that they deem to be material, with due regard to the European Commission’s Guidelines on non-financial reporting: Supplement on reporting climate-related information”. Banks must disclose all material risks related to climate change and, in case they are immaterial, institution is expected to document this judgement with the available qualitative and quantitative information underpinning its assessment.

ECB sets this guide to help financial institutions to be ready to face climate-related and environmental risks, with an appropriate disclosure and assessment of all possible consequences regarding capital and resilience. Looking at greenhouse gases, financial players are expected to disclosure Scope 3 GHG emissions, coming from all the activities and projects banks finance that would lead to a project-to-project approach to measure each carbon intensity, with the consequence of better control of each single

position's emission in the portfolio. Using new KPIs and key risk indicators (KRIs), banks are expected to describe the short, medium, and long-term resilience of their strategies in the light of different climate-related scenarios.

Risks affected	Physical		Transition	
	Climate-related	Environmental	Climate-related	Environmental
	• Extreme weather events • Chronic weather patterns	• Water stress • Resource scarcity • Biodiversity loss • Pollution • Other	• Policy and regulation • Technology • Market sentiment	• Policy and regulation • Technology • Market sentiment
Credit	The probabilities of default (PD) and loss given default (LGD) of exposures within sectors or geographies vulnerable to physical risk may be impacted, for example, through lower collateral valuations in real estate portfolios as a result of increased flood risk.		Energy efficiency standards may trigger substantial adaptation costs and lower corporate profitability, which may lead to a higher PD as well as lower collateral values.	
Market	Severe physical events may lead to shifts in market expectations and could result in sudden repricing, higher volatility and losses in asset values on some markets.		Transition risk drivers may generate an abrupt repricing of securities and derivatives, for example for products associated with industries affected by asset stranding.	
Operational	The bank's operations may be disrupted due to physical damage to its property, branches and data centres as a result of extreme weather events.		Changing consumer sentiment regarding climate issues can lead to reputation and liability risks for the bank as a result of scandals caused by the financing of environmentally controversial activities.	
Other risk types (liquidity, business model)	Liquidity risk may be affected in the event of clients withdrawing money from their accounts in order to finance damage repairs.		Transition risk drivers may affect the viability of some business lines and lead to strategic risk for specific business models if the necessary adaptation or diversification is not implemented. An abrupt repricing of securities, for instance due to asset stranding, may reduce the value of banks' high quality liquid assets, thereby affecting liquidity buffers.	

Figure 12: Climate-related and environmental risk drivers[19]

6.5. STATE OF CLIMATE AND ENVIRONMENTAL RISK MANAGEMENT

A first review was made in November 2021 with "The state of climate and environmental risk management in the banking sector. Report on the supervisory review of banks' approaches to manage climate and environmental risks", that showed institutions have started to reflecting C&E risks in their processes, but few financial players have incorporated these risks into their risk management practices and strategic

[19]ECB (November 2020).

planning with the consequence that, continuing at this pace, banks will be not able to effectively manage climate-related and environmental risks if their practices will not be align with the supervisory expectations.

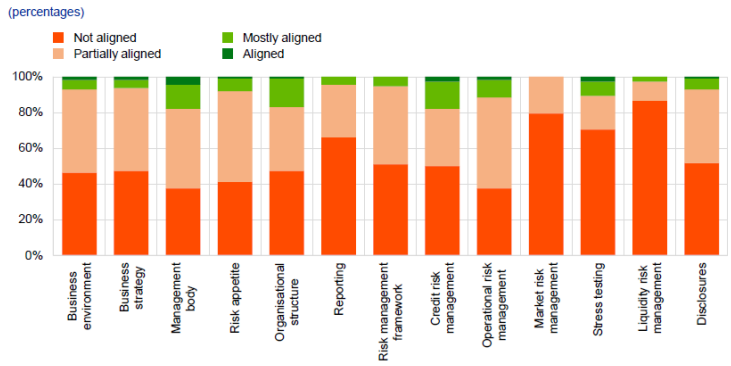

Figure 13: Institutions' alignment with the 13 supervisory expectations set out in the ECB's Guide[20]

The degree of alignment with expectations varies considerably across banks' asset size, where institutions with over €500 billion assets are at least partially aligned in 80% of cases, and in 25% of cases they are at least mostly aligned, instead, financial institutions with assets' base between €30 billion and €500 billion have not already taken steps to integrate C&E risks into their risk decision-making, risk appetite statement and risk classification of exposures, showing that a first step was put in place, but it is not sufficient and, consequently, it will take years to reach the final goals and the full alignment.

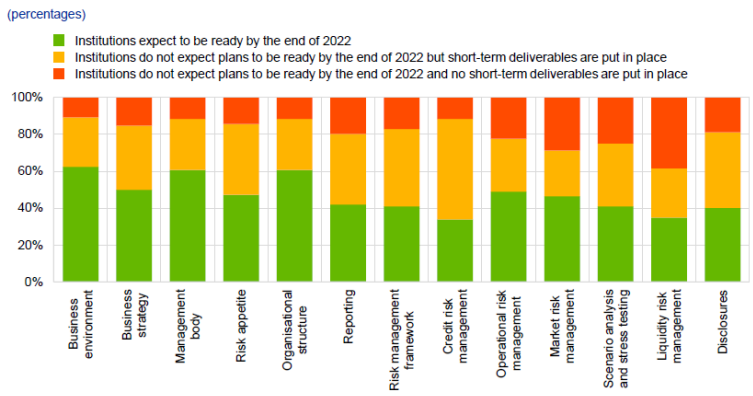

Figure 14: The timeliness of institutions' plans across the 13 supervisory expectations set out in the ECB's Guide[21]

[20]ECB's supervisory assessment.
[21]ECB's supervisory assessment.

7. LITERATURE REVIEW: ECB ECONOMY-WIDE CLIMATE STRESS TEST

After one year from the publication of the thirteen expectations, ECB developed in September 2021 its first economy-wide climate stress test, useful to understand the resilience of non-financial corporates (NFCs) and euro area banks to climate change, with the final aim of define a range of techniques useful to assess the vulnerability of a financial system to "exceptional but plausible" macroeconomic shocks (BIS, 2004), highlighting vulnerability of portfolios to abnormal shocks and market conditions (IMF, 2001).

This document wants to follow an "integrated approach" stress test (BIS, 2004), combining the analysis of the sensitivity of the financial system to multiple risk factors (i.e., transition and physical risks) into a single estimation of the probability distribution of aggregate losses that could materialise under any given stress scenario. The advantages of this approach are the possibility to integrate the analysis of both market and credit risk, but also the likelihood to capture non-linear effects of macro shock on banks' activities that comes from the interaction between transition and physical risks. In this perspective, the assessment and monitoring of the strengths and vulnerabilities of the financial system is called macroprudential analysis (CNB, 2004): this methodology have the aim to use quantitative information on the financial system as well qualitative ones to analyse the possible consequences of climate-related events on financial institutions' portfolio related to capital adequacy, asset quality, earnings and profitability, liquidity, and sensitivity to market risk through a system-wide stress test.

The results showed that short-term costs of transition are lower compared to medium and long-term consequences if firms decide to take no actions, and early adoption of policies to drive the transition to a zero-carbon economy brings benefits in terms of

investment in more efficient technologies. As said in the Journal of Financial Stability (March 2021), climate change introduces new sources of financial risk that come from the absence of sufficient mitigation and adaptation activities, implying an increasing potential for adverse socio-economic impacts across several economic activities and geographic areas, causing disruption to those businesses highly exposed to extreme weather events consequences; the level of magnitude is highlighted in the share of weather-related catastrophe losses that has increased for over 80% of insured catastrophe losses in 2018 (ESRB, 2020), focusing the attention to a prudential risk management perspective with the integration of these new typologies of risks in the decision making process.

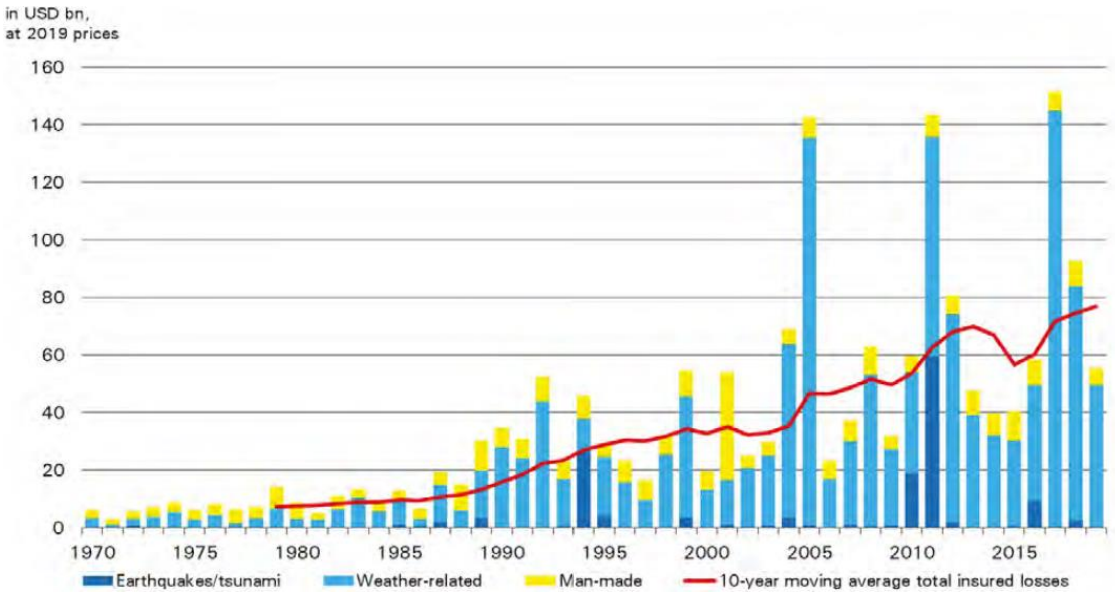

Figure 15: Catastrophe-related insured losses (1970-2019)[22]

ECB paper highlighted also that physical risk would be more prominent in the long run compared to the transition one, due to their non-linearly and irreversible nature, showing the importance of the introduction of policies to favour movement to greener economy to prevent uncontrollable climate issues that could represent the major source of systemic risks, especially for banks with their portfolio concentrated in certain economic sectors and specific geographic areas. As highlighted also by PACTA (July

[22]Impax Asset Management (September 2020).

2021), understanding counterparties' level of commitment to decarbonization efforts can help banks to comprehend their financial risk associated to transition issues connected to the movement to greener technologies. Despite of that, European Central Bank shames banks after finding that none of the 109 lenders it oversees meet its climate disclosure expectations[23], saying that they are producing "a lot of white noise and no real substance", indicating how financial institutions are not preparing themselves to move to an eco-friendly business model able to capture all possible consequences, but also opportunities, coming from climate-related events.

Compared to the previous stress tests made by National Central Bank, looking at the DNB, ECB improved the scope of the analysis, studying simultaneously transition and physical risks and increasing the time horizon, from five to thirty years; instead, comparing ECB and Banque de France, there was a step back, due to the static balance sheet assumption made by European Central Bank, in contrast with the dynamic one used by BdF.

7.1. PILLAR OF ANALYSIS

ECB's economy-wide climate stress test is characterized by four main features, that permit to define the perimeter of analysis:

- It is a centralised exercise.
- It looks at the interactions between transition and physical risks, based on a time horizon of thirty years.
- It has the aim to look at counterparty-level analysis.
- It defines three specific scenarios and how firms and banks will perform in each of these.

[23]Financial Times (March 2022).

It is a centralised exercise, this means it is a pure top-down analysis in which all the information come from internal databases, studied by ECB staff: contrary to a bottom-up approach, where Central Banks need to rely on banks' self-assessment of their exposure, the proposed framework is based on assumptions and models that have been homogenously applied to all euro area financial institutions under analysis, permitting to have a clear and full picture of the current exposure of banks to counterparties.

In contrast with other approaches, ECB decides to focus its stress testing on one out of three methodologies describe by CNB in its paper "Stress testing: a review of key concepts" (2004), the scenario analysis one that permits to assess the resilience of financial institutions and the financial system to exceptional but plausible scenarios that allow to understand both transition and physical risks, as well as the interactions between the two. To consider the physical ones in the right way, ECB decides to adopt a time horizon of thirty years, in order to capture all possible changes of geographic areas where the most emitting firms are concentrated, to have a clear picture of all possible drops in the collaterals' value that banks use to understand their possible loss given default connected to credit exposure; transition risk, instead, is assumed to be dependent on the greenhouse gas emissions and the technology innovations, highlighting again the importance of government interventions to stimulate the adoption of new and more efficient technologies.

For most asset markets, the historical returns do not provide sufficient information in case of extreme events (IMF, 2001), such as the ones connected to climate change: in this circumstance, stress tests permit to aggregate the statistical models' return with information coming from portfolios' behaviour under exceptional scenarios to have a full picture of possible outcomes for financial system.

The stress test wants to capture all the possible consequences for all the euro area financial institutions: reach this goal has been made possible thanks to the creation of a unique dataset that includes all the counterparty-level climate and financial

information, using two ECB tools that are able to identify institutions' exposure at granular level:

- ECB analytical credit datasets (AnaCredit), dataset containing all the information regarding individual bank loans in the euro area.
- ECB Securities Holding Statistics – Group (SHS-G), dataset containing all portfolio holdings at individual ISIN level, including market value and nominal value, and whether the amount will be held to maturity, or it is placed in the trading book.

These two tools permit to map all banks' NFCs exposure, understanding the overall carbon footprint (through Urgentem[24]), physical risk (extracted from Four Twenty Seven database[25]) and financial information connected to counterparties.

Mitigants and amplifiers are also taken into consideration, to have a full picture of possible outcomes: insurance coverages will play an important role for those firms that could have a high impact of physical hazard on tangible assets; insurance risk premium will represent an amplification of costs, especially for companies locate in certain areas and if the worst scenario will happen, that will generate a reduction in profitability and, consequently, an increase in the probability of default, coming from the decrease of margins need to payback interests to banks' loans.

7.2. ELEMENTS OF ANALYSIS

Climate change could affect economy and financial system through a range of different transmission channels: transition risks will affect the profitability and wealth of companies, obliging them to develop new technologies in order to reduce their carbon

[24]Independent provider of emission data, climate risk analytics and advisory services to the finance industry on carbon investment strategies.
[25]Publisher and data provider, market intelligence and analysis related to physical and environmental risks, affiliate of Moody's.

emissions and increase their productivity; physical risks refer to the financial impact of climate change, including more frequent extreme weather events that could be classified in two different ways:

- Acute impacts, coming from extreme weather events that can lead to business disruption and damages of properties; the probability of these phenomenon will rise with global warming and can generate an increase in the underwriting costs for insurers, with a consequent drop in the profitability.
- Chronic impacts, deriving from an increase in the temperatures, sea levels and precipitations, that can affect labour, capital, and agricultural productivity, generating costs related to adaptation for companies and governments.

At micro level, individual businesses will be affected by properties' damages, new capital expenditures due to transition and rising of legal liabilities, from failure to mitigation or adaptation; considering the economy as a whole, there will be an increase in investments related to structural changes, decrease in labour productivity, and socioeconomical changes, such as increase in migration and conflicts.

	Short-term	Long-term
Direct effects	Assets' damage or disruption	Lower productivity
Indirect effects	Effects on corporate value chain	Socio-cultural context's alterations

Figure 16: Climate change's effects on short and long-term

Transition and physical risks are two sides of the same coin: the introduction of new policies might increase the transition issues and costs, with a reduction of financial performance in the short run for companies, but, at the same time, the long-term results, coming from the introduction of greener policies, will generate a reduction of physical risks' consequences that will overcome the initial expenses.

If policy makers and government will not put in place any actions against climate change, the financial system will then see a contagion, where financial institutions will become more capital intensive due to the need of buffer to suffer possible losses coming from credit risk, with an increase in the probability of default and collateral depreciation, and market risk, coming from the repricing of securities connected to the highest emitting firms, that will be more volatile, with an estimation of climate value at risk losses up to 24.2 trillion dollars by 2100[26].

7.2.1. TRANSITION RISKS

Transition pathways, defined in the SR1.5, are modelled using Integrated Assessment Models (IAM), a well-established tool which combine economic, energy, land-use, and climate modules to analyse all the different scenarios that are based on background assumptions: social and economic trends continue in line with historical trends; the Shared Socioeconomic Pathways (SSPs) provide detailed data about the global GDP and population growth, in absence of transition and physical risks.

Figure 17 shows how GDP per capita is expected to grow in the following decades, if no environmental issues will take place; population, instead, is expected to increase with a lower growth rate, that will become also negative after 2060s. This analysis permit to understand the impact that climate change events could have at global level: if no transition and physical risk occurs, the average global GDP per capita will increase, permitting to poor countries to rely on more wealth and increasing their standard of living.

[26]Impax Asset Management (September 2020).

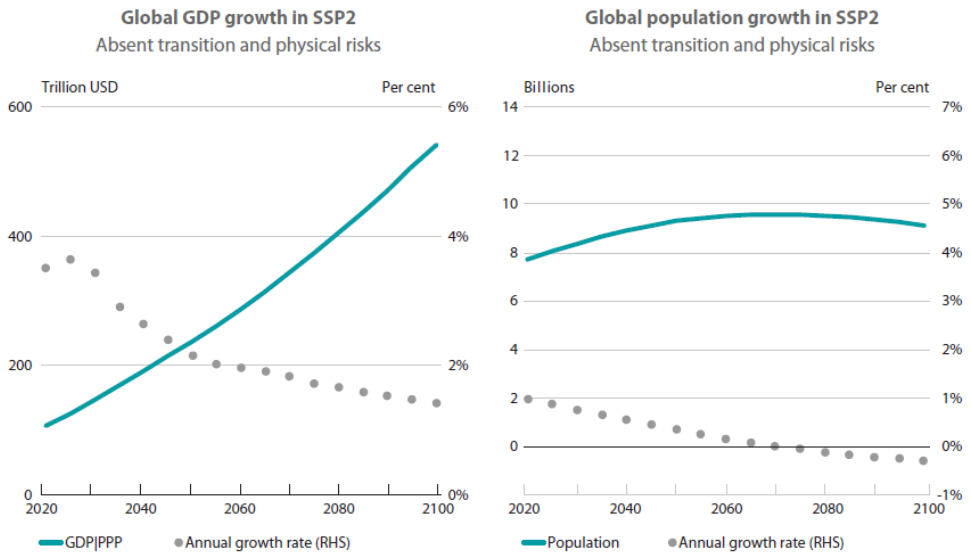

Figure 17: Global GDP and population growth[27]

Other analyses are related to the policy action and technology development: emission prices[28] can be seen as a proxy for government policy intensity, but also timing is fundamental since later will be the adoption of green technologies, highest will be the cost of transition from polluting ones. Carbon dioxide removal technologies play a crucial role in IAM because they permit to understand when and how climate targets can be met and, if CDR will be employed on a large scale, there will be also the possibility to use fossil fuel longer, in order to split investments in more years to have a smaller impact on companies' profitability in the short-term.

In addition to CDR, investments in green energy will be fundamental to reach climate goals: solar, wind, storage technologies, and even nuclear will play a relevant role in the following decades in the energy mix sustainability; if eco-friendly technologies will be adopted, the production of CO_2 coming from industrial process will grow slower in the next years, with a peak in the second half of the century, before the decline, permitting to have more time for firms and governments to put in place new policies to prevent future environmental issues.

[27]IIASA NGFS Climate Scenarios Database, GCAM model.
[28]Define as the marginal abatement cost of an incremental ton of GHG emission.

7.2.2. PHYSICAL RISKS

Physical risks can be defined as “those risks that arise from the interaction of human and natural systems, including their ability to adapt” (Batten et al., 2016); estimation about GDP losses from physical risks vary considerably, depending on when the green technologies will be adopted; mean temperature rise is connected to the concentration of greenhouse gases in the atmosphere and the higher temperatures will generate heavy precipitation across many regions, with an increase in the risk from flooding.

Annual maximum discharge in a river is a measure for fluvial flood risk from heavy precipitations; firms with their immobilize properties closed to these geographical areas will see a huge increase in the probability of natural disasters, with a consequence of physical assets’ damages. Other risks can also be connected to extreme heatwaves, cyclones, with an increase of 1-10% of wind speeds, and sea levels, that are hypothesised to continue to rise for centuries after having reach the net zero.

To protect against physical risks, insurance coverage is limited, and historical data shows that only part of economic losses from natural disasters is protected by insurance policies; according to Swiss Re (2020) global economic losses from natural catastrophes were $137 billion in 2019, and only 38% was covered by insurance, showing the relevance of this topic for banks’ credit risk.

To find alternative sources of capital to bear potential losses, insurance-linked securities (ILS) and, in particular, catastrophe bonds have been developed, permitting to transfer risks associated with natural disasters to investors through global financial markets. These particular forms of securities based their payoff on a trigger event, such as wind speed or rainfall, rather than a measure of loss, allowing issuers to pay out quickly and cover the financial impacts, making these financial instruments relevant in the context of transmission channels for banks.

If policies to transition toward eco-friendly economy will not be introduced, physical risks become increasingly higher over time due to their nature, with an increase that can be assumed non-linearly, with consequences that irreversible natural and climate changes will become more consistent over years, generating instability for financial institutions and for non-financial firms highly expose to carbon emission activities.

7.3. SCENARIOS UNDER ANALYSIS

ECB decides to analyse transition and physical risk running three particular scenarios, investigating how banks liquidity and capital would be affected in case of climate change, and the resilience of NFCs. The starting point are the frameworks proposed by the Network for Greening the Financial System[29] (NGFS), in June 2020 that includes three representative possibilities, analysed in two dimensions, transition pathway and physical risks:

- Orderly transition scenario, where both transition and physical risks are low and it is possible to reduce emissions immediately, in a way to meet climate goals.
- Disorderly transition scenario, in which physical risks are not heavy, but transition actions are late and unanticipated, but sufficient enough to reach the net zero.
- Hot house world scenario, where firms continue to increase emissions, with very few actions to mitigate both physical and transition risks, with a consequence of a significant global warming and severe physical issues.

[29]NFGS (June 2020).

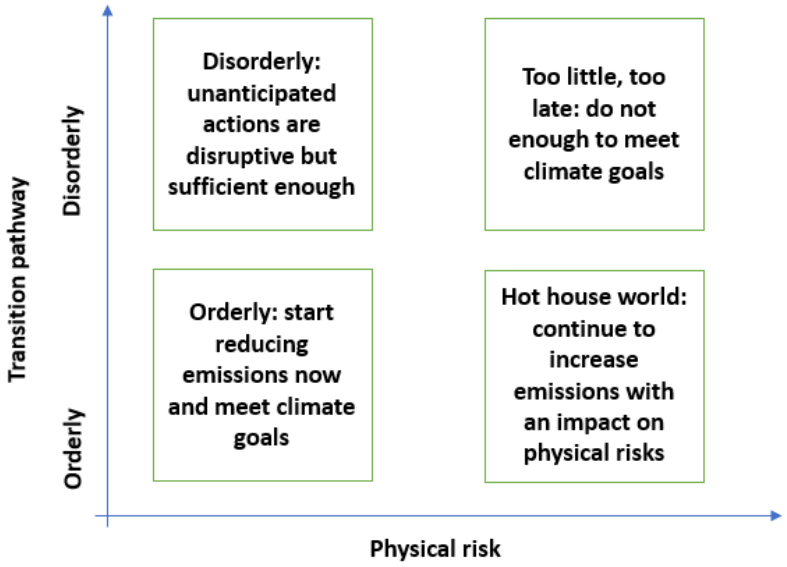

Figure 18: Scenarios under analysis

These three scenarios are chosen to show all the possible combinations between different actions, with the case of "Too little, too late", that represents the most catastrophic situation, not under analysis.

The orderly transition scenario represents the best-case situation in terms of potential economic impact; it assumes climate policies are introduced early and they will become gradually more stringent, with the final aim to meet the Paris Agreement target by the end of the century.

By contrast, the hot house world scenario represents the worst-case possible, where there will not be regulators' interventions, and only the current policies are preserved; national contributions to reach the reduction of carbon emissions will not be sufficient and they will continue to grow until 2080, leading an increase of 3 °C[30], with also severe physical risks. In this case, the costs associate to transition issues will be null, but the savings coming from no-transition are more than offset by costs relate to natural catastrophes that will be extremely high.

[30]NFGS (June 2020).

In the middle of the two cases, there is the disorderly transition scenario that assumes delayed implementation of climate policies; in this situation, global warming will start to be mitigated only from 2030, new technologies will be introduced later, and the result will be higher transition risks compared to the best-case scenario.

These scenarios are analysed looking at macroeconomic and climate projections of real GDP, GHG emissions, energy prices and consumption.

Starting from the first one, the differences between the projected level of best-case scenario's Gross Domestic Product and the other two become wider over the forecast horizon: looking Figure 19, graph on the left, in all scenarios GDP is expected to grow, but, analysing the graph on the right, the consequences of hot house world scenario generate a reduction of GDP equal to 6% compared to the baseline, offsetting the initial higher Gross Domestic Product that the worst case will have during the 2025s. Disorderly transition's projections, instead, provoke a reduction only about 3%, minimum point that will be reached during the 2055s, that will be maintained constant in the following years, in line with the late adoption of green technologies that permit to stabilize the global context.

Figure 19: ECB calculation based on NGFS climate scenarios[31]

In the short-term, macroeconomy results will be influenced especially by transition costs, whereas damages coming from natural catastrophes will appear only at a longer

[31]ECB calculation based on NGFS climate scenarios (2020b).

horizon, with significant impacts on GDP. For this reason, in the very short-term, Gross Domestic Product connected to the hot house world scenario will increase more compared to the baseline one, that because it is assumed that the worst possibility is associated with negligible or inexistent expenses related to the prevention of climate risks. However, in the medium to long-term, the macroeconomic costs associated to physical risks will become more and more relevant: the impacts connect to physical damages are limited to no more than 2% of European GDP in case of disorderly scenario, in contrast with a decrease of 10% in the hot house world one, as shown in Figure 20.

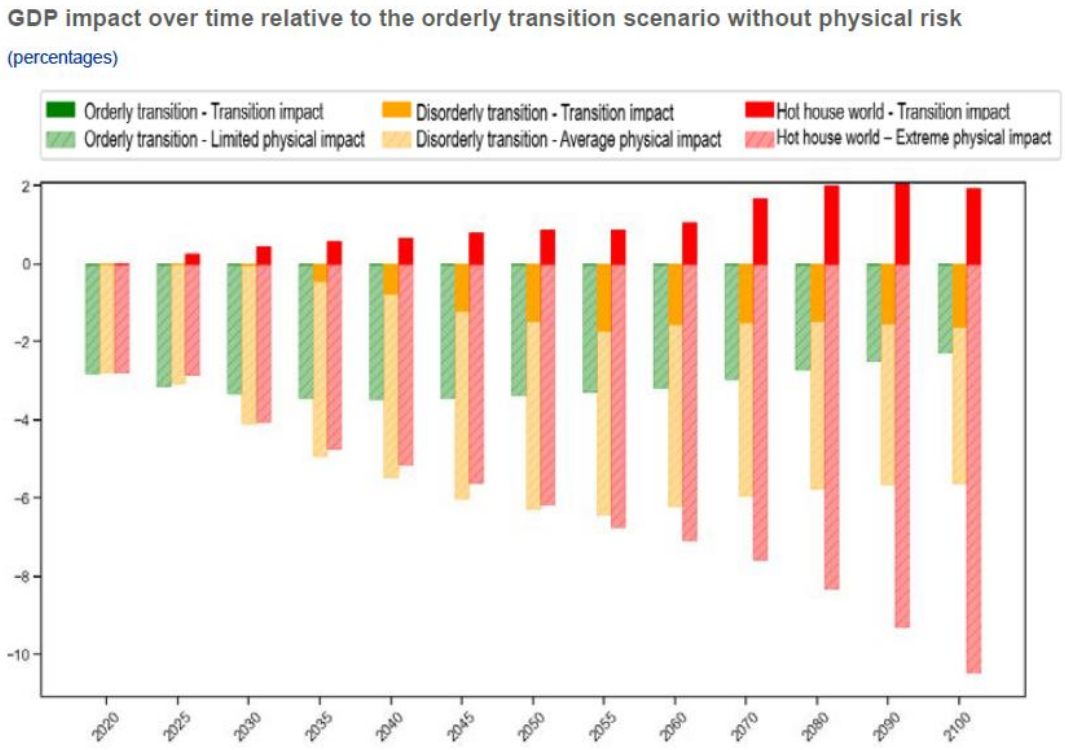

Figure 20: Decomposition of real GDP between physical and transition risks[32]

Figure 21 shows the nature of physical risk in case of hot house world scenario: the cumulative GDP loss at 2100 is equal to 25%, highlighting ones again how much the

[32]ECB calculation based on NGFS climate scenarios (2020b).

transition and the early adoption of greener technologies is fundamental, and the initial costs will be lower and lower compared to long-run consequences.

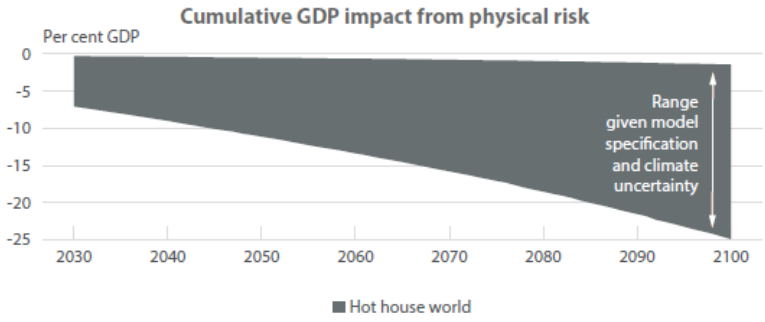

Figure 21: Cumulative GDP impact from physical risk[33]

The second element taken under analysis by ECB is GHG emissions: projected levels of carbon emissions in the hot house world scenario are well above compared to the other ones. Looking at the orderly and the disorderly situation, the difference is due to the late access to carbon dioxide removal technologies; to better analyse the situation, it is reasonable to assume that, in the best-case scenario, CDR technologies are fully available, instead, in the disorderly one, firms have access to limited technical knowledge to reduce their impact, in the same timeframe.

Figure 22 shows how, initially, GHG emissions in the disorderly scenario are higher compared to the orderly one, but, from 2040s onward, greenhouse emissions of baseline scenario are more compared to the intermediate one taken in consideration: it could be reasonable to think that this situation happens because, in the disorderly scenarios, characterised by late adoption and, consequently, worst environmental situation, CDR technologies will be adopted by all firms when they become accessible, instead, in the orderly scenario, the adoption will be more smoothly, with the consequence of reaching net zero later, even if it represents the best case. The other side of the coin, instead, might be represented by the costs associate to the rapid and full adoption of greener technologies in the disorderly scenario compared to the orderly one: in the latter, in fact, investments are divided in more years, with a results of higher

[33]PIK calculations based on damage function model specifications from the wider literature.

profitability looking at year-by-year results; instead, in the former case, due to the need to introduce eco-friendly technologies as soon as possible, firms will face a drastic drop in profit generation, due to huge investments needed with a lower time horizon in which they could split costs.

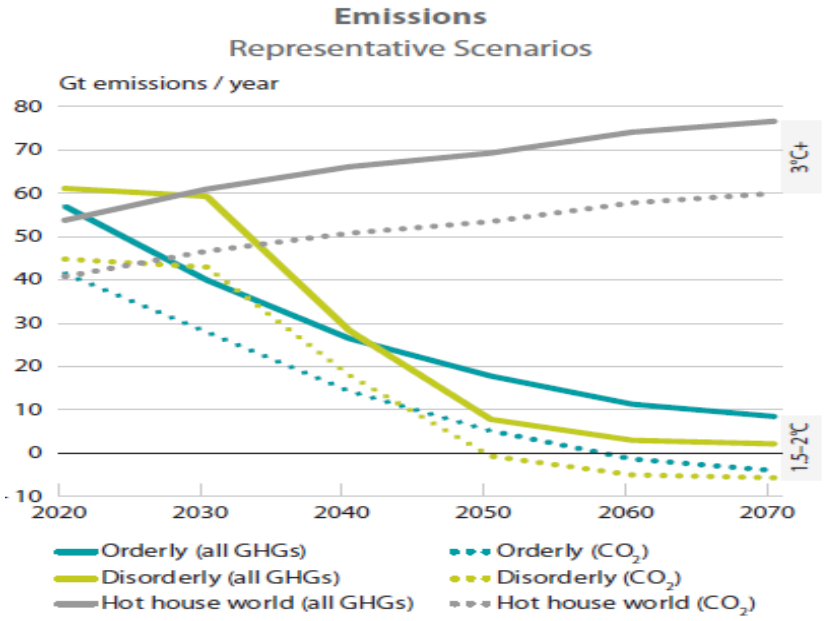

Figure 22: Representative emissions' scenarios[34]

From the supply side, green energy will be produced more efficiently under the orderly transition scenario with a fall of energy price compared to the worst case. A timely usage of eco-friendly technologies will generate a double effect: not only a reduction of energy prices, but also a decrease in the energy consumption; in fact, a delayed introduction of clean power will provoke an increase in the projected energy consumption path in the worst-case scenario, compared to the decrease that is showed in Figure 23 looking at the other two situations.

[34]IIASA NGFS Climate Scenario Database, using marker models.

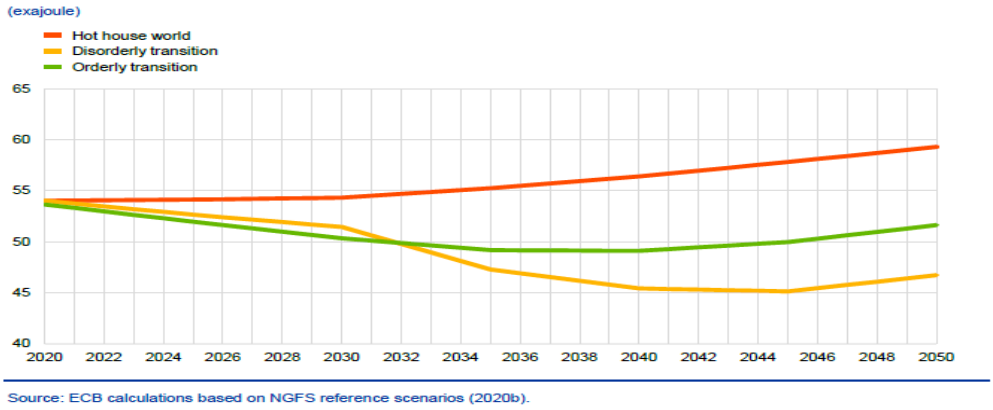

Figure 23: Projected energy consumption paths[35]

7.4. CONNECTIONS BETWEEN CLIMATE CHANGE AND CREDITWORTHINESS

European Central Bank decides to look at three particular types of firms to run its climate change stress-test: median European firms, highest emitting firms, and highly exposure to physical risk firms. ECB wants to assess the profitability and the solvency of non-financial companies, analysing granular information on individual firms' carbon footprint and vulnerability to physical risks, taking also into account costs associate with technological changes and energy efficiency.

On one hand, firms can decide to use mitigants to protect themselves from physical damages, with an increase in the importance of corporates' insurance coverages; on the other hand, an elevate probability of natural disasters could generate higher insurance costs, especially in the most vulnerable areas and in the hot house world scenario.

More consideration of physical risks will also influence the financial system, where banks will face an increase in the aggregate default probability of credit portfolio, and possible losses from corporate bond repricing could happen: in fact, in order to be ready for the transition, firms may increase their leverage, using new debt to cover expenses

[35]ECB calculations based on NGFS reference scenarios (2020b).

coming from new technology adoption, or new insurance policies incorporation to cover physical risks.

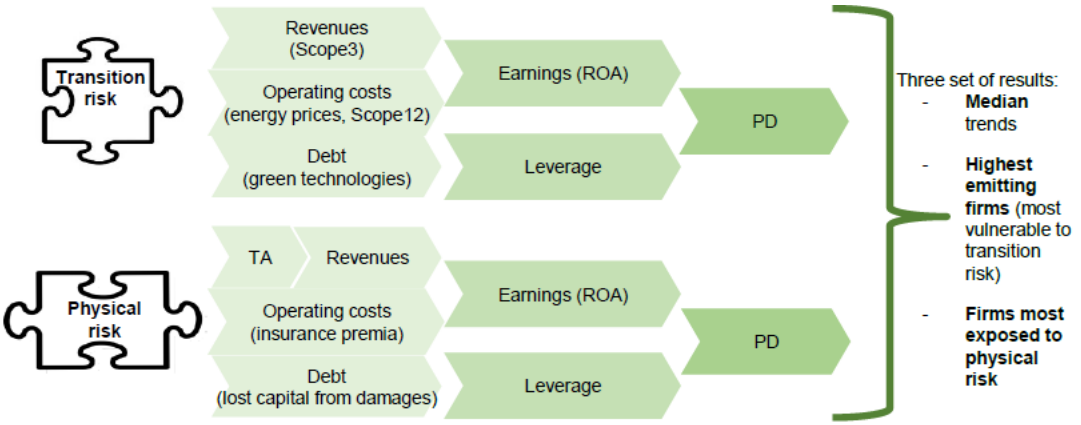

Figure 24: Schematic overview of climate risk to firms through credit risk[36]

The most relevant point under analysis for credit risk is the probability of default that each firm will have in all three scenarios, coming from an integration of the consequences deriving from transition and physical risks.

Transition risks generate impacts both on the supply and demand side: for the latter one, purchasing goods, whose production generates huge GHG emissions, will become more expensive, assuming an increase in carbon prices, coming from a flat carbon tax; in this situation, firms' earnings may decrease, with a decline proportional to Scope 3 emissions. On the supply side, companies will face higher costs coming from transition to cleaner technology, and firms' operating expenses will grow proportional to their specific Scope 1 emissions; climate policies will also have impact on energy price, that will increase as function of Scope 2 emissions, that can be used as proxy of energy consumption. Overall, the potential introduction of a carbon tax would increase the costs for firms, especially if their activities come from the polluting sectors; however, the transition risks and expenses will be offset by greener and more efficient technologies that, in the following years, will generate benefits higher compare to the initial adoption costs.

[36]ECB (September 2021).

Leverage may also increase under the transition scenarios: firms need to invest to replace their existing production processes and to switch to eco-friendly technologies (e.g., carbon removal technologies) that could help companies to decrease their GHG emissions, also reducing the potential carbon tax's effects on their profitability.

Also, physical risks directly affect revenues and operating expenses of firms, touching other aspects: higher will be the probability and the magnitude of natural disasters, higher will be costs associate to insurance premium and maintenance of property and plant, thereby leading to a reduction of operating margin. Natural catastrophes will generate physical capital losses, that will require new investments, exerting upward pressure on leverage; at the same time, firms' revenues may decline, due to productivity's reduction, coming from bad external conditions. In this scenario, a new variable connected to the building geographic position will be needed to be introduced in the decision-making process, especially if, at global level, no significant actions will put in place, with a consequence of increase in temperature and probability of natural disasters, that will be higher in specific geographic areas.

On the financial institutions' side, banks' calculations of expected losses coming from physical risks combines two different aspects: the direct impact of extreme weather events on firms' profitability (e.g., frequency and intensity of flooding, wildfire, and sea level rise) with indirect impacts, such as GDP reduction of specific geographic areas, coming from natural disasters, or chronic changes in temperatures and precipitations. In this framework, as expected, the damages will be higher in the hot house world scenario, compared to the disorderly and the orderly ones, as shown in Figure 25: even if these extreme events are expected to affect only a low number of firms, the transmission channel to the rest of economy might generate huge aggregate impacts on the system, especially in the long run, if climate mitigating policies will not be introduced.

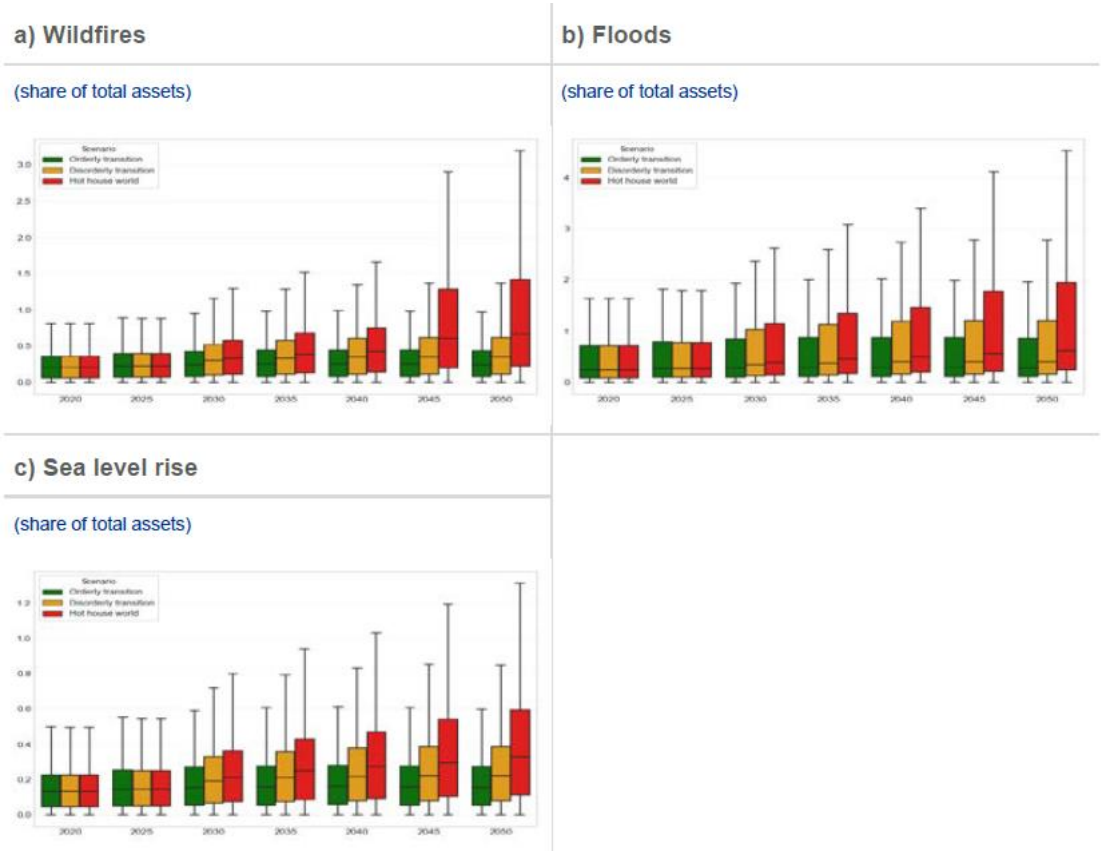

Figure 25: Expected losses coming from natural hazards[37]

7.4.1. MEDIAN EUROPEAN FIRMS

The starting point of the analysis are the median European firms, to have a glance of the current situation: median companies will be less indebted, more profitable and will have a lower probability of default (PD) at the end of the time horizon under the orderly transition scenario as compared to the other two adverse situations.

Instead, in case of hot house world scenario, leverage will strongly increase, in order to face losses coming from natural disasters, and profitability will decrease up to 40%, due to decline in production, coming from extreme events; as combination of these two

[37]ECB calculation based on NGFS scenarios (2020b) and Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).

factors, the probability of default in the worst scenario could be up to 6% in 2050, compared to the orderly transition.

Looking at the disorderly one, it would be better compared to the hot house world, but it will result in higher leverage and lower profitability by contrast with the best-case, due to later adoption of technological improvements, generating a higher PD in comparison with the orderly scenario.

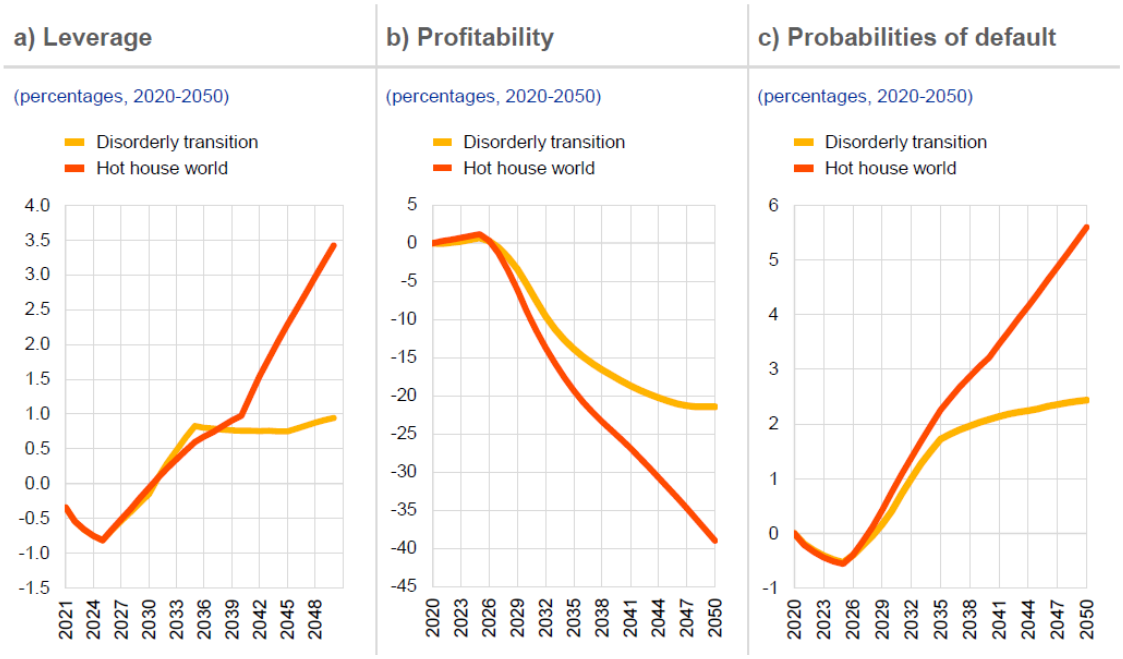

Figure 26: Projected results for the median European firms[38]. All charts display median percentage changes under the disorderly transition and hot house world scenarios relative to the baseline (orderly transition)

PD growth reflects costs that firms would face to comply with green policy that will be introduced under the period of analysis, driven by carbon taxes and technological substitutions that will have a direct impact on companies' profitability.

Leverage will increase consequently, due to two main reasons:

- Implementation of green technology, that is assumed to start in 2020s in case of orderly scenario and in 2030s in case of disorderly one.

[38]ECB calculation based on NGFS scenarios (2020b) and Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).

- Increase in the probability of extreme events that will provoke damages on physical assets, effects that will be more pronounced in the hot house world case, especially in the second half of the projected horizon.

Looking at Figure 26, graph a, leverage's change indicates that the investments needed are affordable for median firms, with an increase only about 1%, comparing the best-case with the disorderly scenario, and this growth will be cheaper than the costs of sustaining increasingly higher damage from physical risks, estimate around 25% in 2050; the hot house world scenario is characterized by a leverage increase of 3.5% compare to the orderly one, indicating that firms that will not take actions against climate change will face consequences coming from long-term risk (e.g., physical risk) more significant compared to the other two cases, with leverage growth more than three times higher compared to baseline.

Analysing graph b, also profitability is better in case of early adoption, due to less revenues' shocks and operating costs. Only during the first few years companies' earnings under hot house world scenario will be higher, due to no costs associate to the adoption of new technologies and lower interests to be paid on leverage, but the situation will be reversed at the end of 2050, where profitability will drop about 40% compared to the best-case; the increase in the companies' result in the medium and long-run in case of orderly scenario is made possible by the efficiency gains from green transition and less damage from physical risks, that help to prevent global damages at environmental level. Analysing the disorderly situation, it shows a decline in profit about 20%, driven by worst energy mix, but a half compared to the worst-case, showing again the effects of physical risks in the long run.

The projected probability of defaults combines the results of the two effects above, showing that the potential impact of no climate action could generate a drop of creditworthiness at the end of the time horizon closed to 5.5%, in case of hot house world scenario, and 2.5% in the disorderly one.

Median firms will have a higher PD in the orderly transition scenario only during the first years, where companies will start to make their investments, increasing leverage before the other two scenarios under analysis; however, after a first period of assessment, the benefits of an early adoption will become more consistent, and the probability of default will drop compared to the two adverse scenarios.

7.4.2. HIGHEST EMITTING FIRMS

High emitting firms are defined as the top 10% firms with the highest intensity of CO_2 emissions: in this sample, the leading sectors are agriculture, manufacturing, electricity and gas, wholesale and retail, and mining, which together account for almost 70%. The right panel in Figure 27 shows the percentage of firms in each sector that are high-emitters, and it is possible to notice how the percentage of mining is small in the total sample, but every single company is a high-emitting one, meaning that this sector will need a drastic change in the business activities.

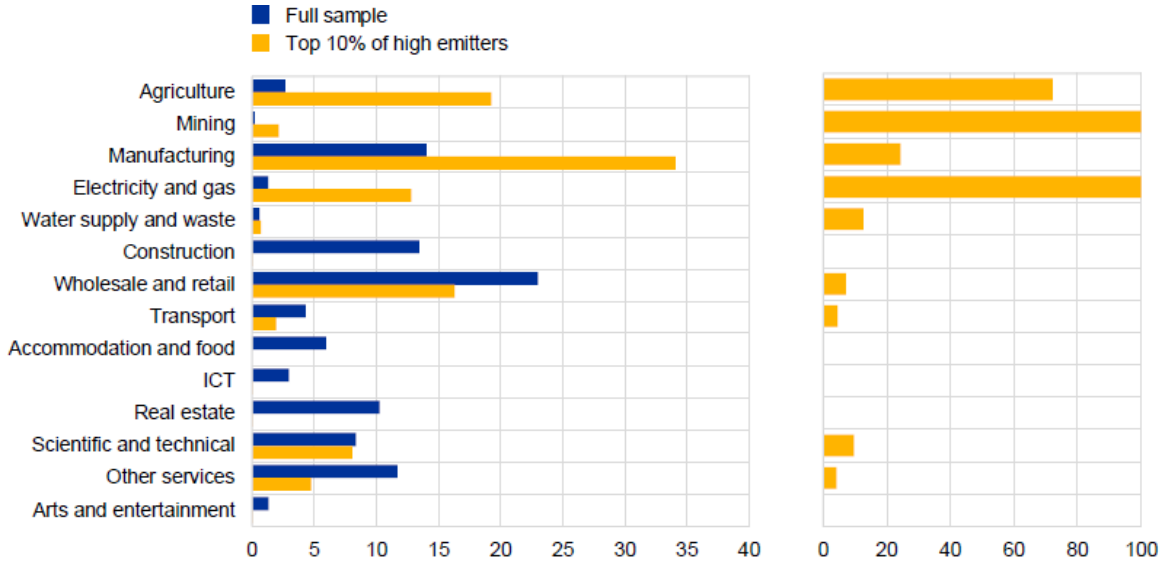

Figure 27: Sectoral breakdown comparison between the full sample and top 10% of high emitters[39]

[39]ECB calculation based on NGFS scenarios (2020b) and Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).

The main difference between median and highest emitting companies is the need to raise more capital during the transition phase in order to replace technologies with eco-friendly options: this will be translated in higher leverage and more differences across the three scenarios under analysis, as shown in Figure 28.

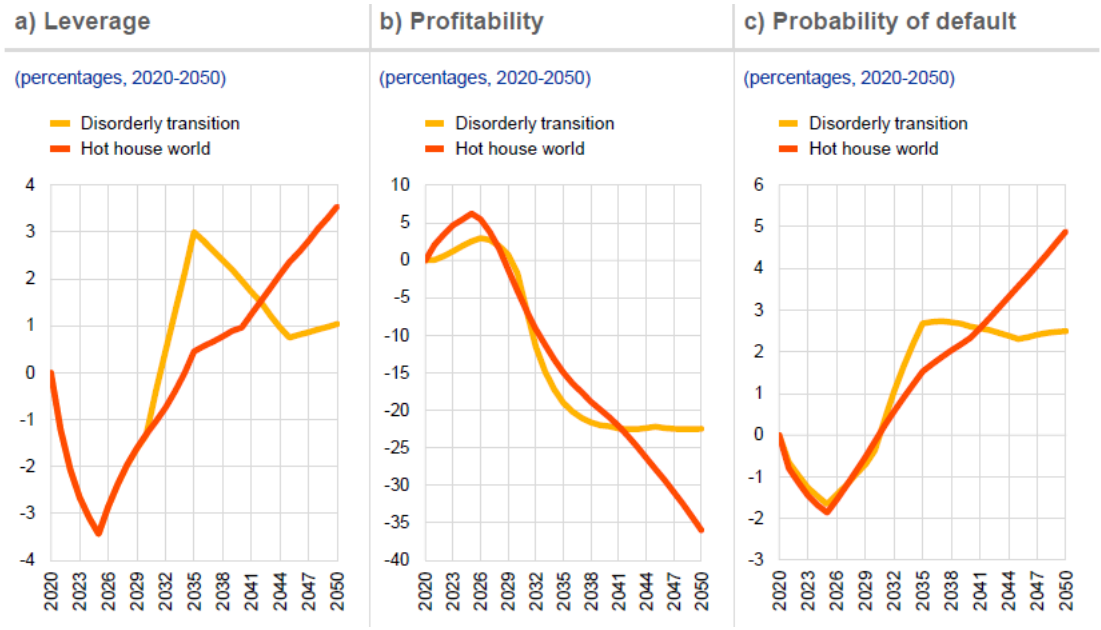

Figure 28: Projected results for carbon-intensive European firms[40]. All charts display median percentage changes under the disorderly transition and hot house world scenarios relative to the baseline (orderly transition)

The higher impact of costs related to investments is shown in graph a, where the first decade is characterized by a decrease in the debt's level of the two worst scenario compared to the baseline due to no investments, but the main effects of climate change appear in the long-run, where, in the hot house world scenario, leverage will increase more than 3% compared to the best-case, mainly due to investments needed to face physical risks that will appear; in the disorderly one, instead, there will be a peak during the 2030s, coming from a late and rapid adoption of green technologies, but at the end of 2050 the difference compared to the orderly scenario will be only about 1%, meaning that there can be a possibility of recovery also in case of late adoption.

[40]ECB calculation based on NGFS scenarios (2020b) and Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).

Short-term profitability is negative correlated to leverage: firms that will decide to not make investments will face a higher profitability in the first years however, in the long run, the impacts of climate change will be higher and higher, with a decline of more than 35% in case of hot house world scenario. Transition to eco-friendly technologies will have a strong impact on highest emitting firms' earnings: graph b of Figure 28 shows how bigger will be the influence of carbon tax on both revenues and operating costs in the two scenarios compared with the orderly one.

The probability of default, shown in graph c, will decline in the first decade compared to the best-case, due to the combination of lower leverage and higher profitability; looking at long-term, instead, the benefits of climate mitigation actions will be more consistent, and the transition costs would lead to an increase of PD of 5% during hot house world scenario, compared to the orderly one.

The main difference with the median European firms situation comes from the comparison between Figure 26 and Figure 28: looking at the average situation in Europe and at the graphs of the three elements under analysis, the hot house world scenario is always higher compared to the disorderly one, meaning that, both in short and long-term, later will be the adoption of green technologies, higher will be the climate change consequences on companies; instead, analysing the highest emitting firms sample, the impacts on leverage, profitability and probability of default will be higher in case of disorderly transition until 2040s, and only in the last decade under analysis the hot house world scenario will become the worst case, highlighting once again the relevance of physical risks in the long run as compared with the transition ones, especially in sectors where the level carbon emissions are higher compared to the global average.

To better understand how these carbon emission intensive sectors will be influenced, it is possible to take a snapshot of coal mining industry, the highest emitting activity. As shown in Figure 29, looking only at orderly and disorderly transition, the impacts of transition will be stronger compared to the median firms: moving to a green

economy would require an increase of leverage about 90% and 70% under the orderly and disorderly scenario, respectively, from the initial 27%, against an increase of only 1-2% looking at median companies; also the probability of default will increase by 150% in the best-case, from 2% to 5%, and 100% in the disorderly one.

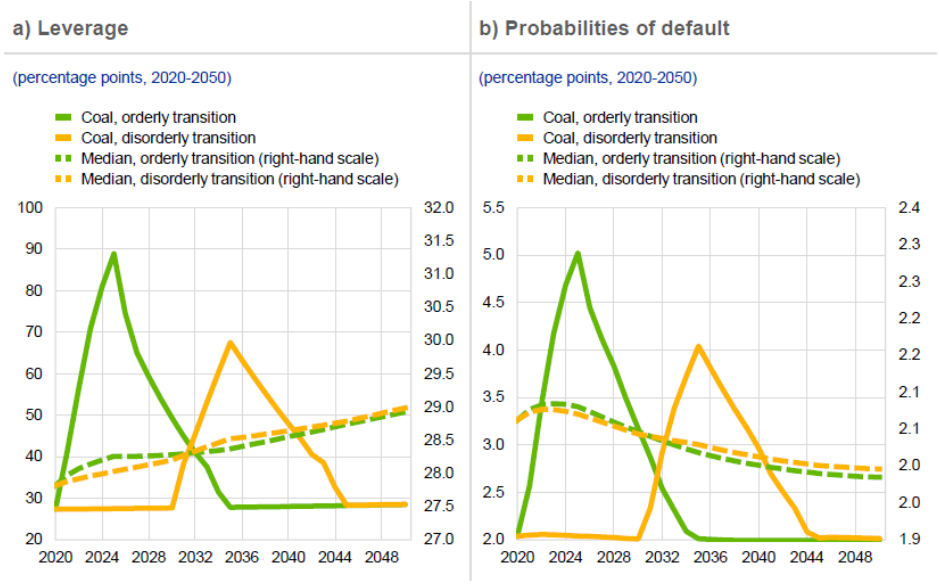

Figure 29: Projected results for coal mining activities (NACE B05) as compared with the median firm[41]. The simulation does not consider the reduced demand for coal in the future in case of green transition.

Comparing the results of coal-mining firms with the other highest emitting companies, they represent a strong outlier, since the emission intensity is several orders of magnitude higher than the next most polluting sector; analysing their Scope 3 emissions, coal firms produce 20,000 tonnes of carbon dioxide per million dollars of revenues, whereas for all other sectors of economy fall below 3,000 tonnes for the same statistic. This level of pollution will generate an acute impact on leverage and probability of default, obliging companies to invest large sum in carbon removal technologies that offset the burning of coal that they extract.

[41]ECB calculation based on NGFS scenarios (2020b) and Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).

This snapshot helps also to understand how each sector is different from another one, and this will generate two effects, one connected to firms' activity, and one connected to banks:

- Firms need to change their decision-making progress and their business model, trying to move to a greener one, in order to preserve their profitability and financial stability in the long run.
- Banks will be obliged to develop an ad hoc rating system in which they could understand the current situation of firms, also comparing them with their specific industries; financial institutions need also the modify their risk appetite framework, taking into consideration if they want to be exposed to high emitting companies or not, with consequences in their capitalization request.

7.4.3. HIGHLY EXPOSURE TO PHYSICAL RISK FIRMS

The cluster of firms most vulnerable to physical risks includes the 10% of firms that are most exposed to physical damage over the thirty-year projected horizon; these types of firms would benefit strongly from an orderly transition given the consequences of severe natural disaster that could happen if no action will be taken, affecting their financial performances.

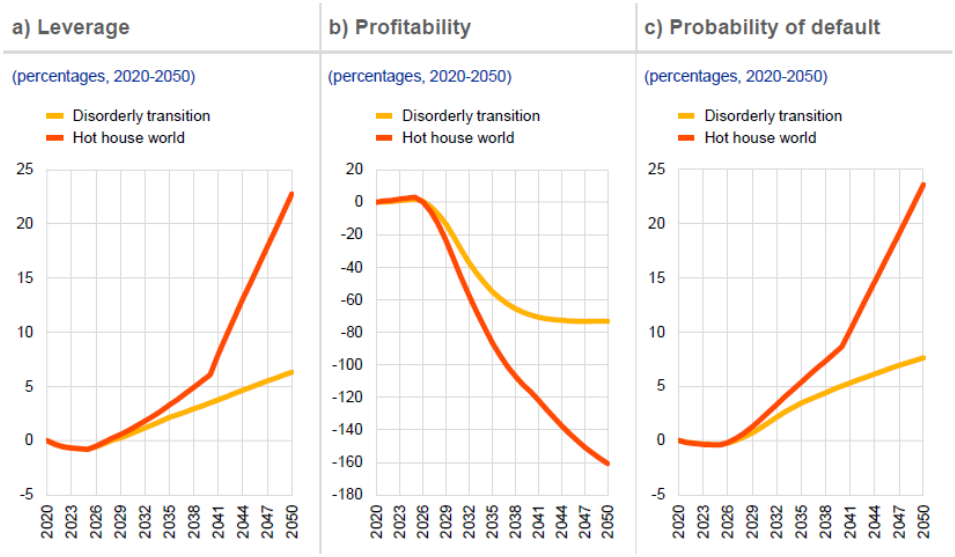

Figure 30: Projected results for firms most vulnerable to physical risks[42]. All charts display median percentage changes under the disorderly transition and hot house world scenarios relative to the baseline (orderly transition).

Firms highly exposed to physical risks will suffer from a huge increase in leverage over the medium and long-run period, due to increase of damages coming from natural disasters that will affect assets, obliging them to do investments to repay their buildings. By 2050, leverage is projected to be 22.5% higher in the hot house world scenario as compared to the orderly one, that is seven times larger compared to median European and carbon-intensive firms; this highlights damages from physical risks will be more consistent and more capital intensive compared to transition risks, that have a very minor role.

High-physical-risk firms would also experience the largest drop in profitability as compared with the other two samples in case of no policy intervention, with a decrease closed to 160% compared to the base-case; this effect is generated by a huge increase in operation costs, coming from new and costly insurance premiums that firms will face to protect themselves. At the same time, companies need also to recover from natural disasters that would affect their physical assets, with a disruption on their supply chain, leading to a decline in revenues.

[42]ECB calculation based on NGFS scenarios (2020b) and Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).

Graph c of Figure 30 shows the projected probability of default in 2050, that will be five times larger than what is observed for median and high-emitting firms, reaching an increase of 25% compared to the orderly scenario.

This third group under analysis represents the one most expose to climate change consequences connected to physical risk: the huge increase in leverage represents how much firms need to pay to protect their building against future losses coming from depreciation due to natural disasters, underwriting new insurance policies or repair the immovable properties. Leverage could also be used to change the geographic location of companies' buildings, introducing this new variable in the risk assessment approach, in order to reduce operating costs related to environmental issues.

7.4.4. WRAPPING UP

Collecting all the information about the three scenarios and the three typologies of firms, physical risks will be the main driver for financial instability in the future, especially in case of no climate policy interventions and in specific geographic areas: southern European countries would face more water stress, heat-stress and wildfires, instead middle-to-north European countries will be mostly affected by flooding risk.

Looking at the average probability of default at the end of time horizon relative to the orderly scenario, the expected effects from physical damages can range from 5%, in case of highest emitting firms in hot house would scenario, to 25%, looking at firms mostly exposed to physical risks.

As shown in Figure 31, the variation in the end-of-horizon probability of default is larger between sectors, from 2% in information and communication to 8.5% in agriculture that represents the most affected industry, where climate change will strongly affect revenues that depend heavily on temperature and natural disasters. The

second cluster of firms are strong asset-based, from the wholesale and retail industry to the manufacturing one: in these cases, the increase of probability of default is closed to 6%, mainly due to physical damages that will affect profitability, increasing insurance premium or costs to face damages on buildings.

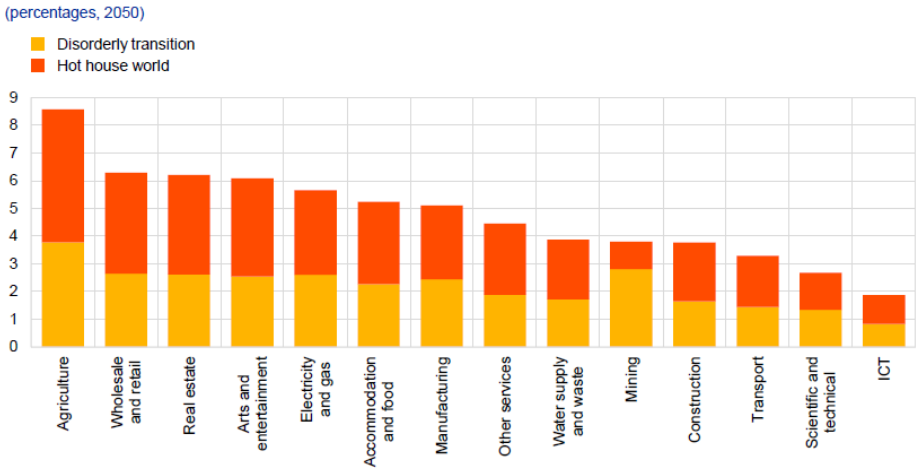

Figure 31: Probabilities of default relative to the orderly transition scenario by sector[43]. Median percentage changes under the disorderly transition and hot house world scenarios relative to the baseline (orderly transition).

Overall, the impacts of transition scenarios on firms' financial are heterogeneous across sectors: however, while some firms will be affected by harder transition costs than others, all sectors will benefit from adopting eco-friendly technologies.

Nowadays, risk managers are obliged also to consider energy transition risks in their analysis since they are no longer negligible, and every bank needs to start to run its climate change test to gain a sense of vulnerability; postponing action will only increase the risk of abrupt losses in the future that will affect banks' stability and profitability.

[43]ECB calculation based on NGFS scenarios (2020b) and Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).

8. SSM STRESS TEST 2022

After the top-down climate change stress test, in October 2021, ECB published the Single Supervisory Mechanism (SSM) Stress Test 2022, a document that wants to describe an uniform methodology for conducting a bottom-up exercise with the aim to identify the best practices and limitations banks are facing, to understand financial institutions' level of preparedness, and how they envisage to adjust their business models in the face of climate risks, with the final goal of SREP[44] integration focusing on qualitative aspects coming from environmental issues.

ECB wants that banks take into account how their business model will change in light of transition risks and financed GHG emissions, identifying four main scenarios: transition risks based on NGFS scenarios, identifying short-term tail risks (3 years) and long-term transition paths (30 years), and physical risks for Europe, looking at flooding risk (1 year) and heat & drought risk (1 year); the final output will be a climate risk stress test capabilities, where banks are able to identify impacts from credit and market risks, but also operational and reputational ones.

The exercise will be conducted from March 2022 to July 2022, and it will comprise three main phases:

- Data collection, where ECB will provide a template to single banks, and they are required to complete it, verifying and meet the standards set out in the document.
- Quality assurance, in which European Central Bank will analyse the information submitted to ensure satisfactory quality, alignment with the instructions, and comprehensive and reliable results for the prescribe assumptions and scenarios.
- Computation of results, to identify the current situation and the possible outcomes of the stress test.

[44]Supervisory Review and Evaluation Process.

The climate risk stress test consists of three modules: Module 1 is a qualitative questionnaire, uniform and standardized, that wants to assess the banks' climate risk stress testing framework; in Module 2 banks are requested to calculate climate metrics, for benchmarking them across a common set of climate risk metrics; Module 3 represents the bottom-up stress test projections. All significant institutions are subject to Module 1 and Module 2, but only a subset of participants is expected to conduct Module 3.

Compared to the previous economy-wide climate stress test, published in September 2021, this exercise follows a bottom-up approach, where banks need to provide all data to supervisory institutions to analyse them; this change will help financial players to better incorporate climate-related and environmental risks into their business strategies and into their governance and risk management framework. Addressing risk stemming from climate change will be one of the main challenges for banks and supervisors in the next decades, and this SSM represents one of the first milestones to face transition towards a low-carbon economy, permitting to analyse exposures of banks to firms with high carbon emissions and consequences on financial stability; the publication of this paper emphasize the importance for banks to be ready to face changes in the global context, where energy transition and firms' movements from their core business to new activities will represent a future trend that will permit to reach carbon neutrality and reduce risks associate to extreme climate events.

8.1. MODULE 1: QUALITATIVE QUESTIONNAIRE

The purpose of the first module is to assess banks' internal climate risk stress test framework in line with expectation 11[45] set out by ECB in November 2020, providing supervisors new insights into individual bank's internal climate risk stress test

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

capabilities as well as industry-wide best practices in terms of internal climate risk stress test framework; the questions concern qualitative information on the institutions' current process and they are classified in eleven blocks where, from block 1 to block 10, topics are based on day-to-day internal stress testing framework, while block 11 concerns the assumptions developed by the bank in the context of the 2022 climate risk stress test exercise.

The eleven blocks are:

- Block 1: General climate risk stress test, that includes general questions regarding existence and usage of climate risk stress testing within the institutions, with the aim of analyse if the current risk management framework is able to capture all possible changes regarding environmental issues.
- Block 2: Climate risk stress test governance and risk appetite, looking at business areas involved in the development, execution, and validation of the climate risk stress test framework, to better understand if financial institutions have the capabilities to capture and analyse changes regarding climate change.
- Block 3: Integration of the climate risk stress test into the institution's long-term business model strategy, analysing how banks will integrate the result in their process, helping banks to develop a new perspective that takes into account also climate change risks and opportunities.
- Block 4: Stress test methodology, that includes assumptions, transmission channels and portfolios used in the climate risk stress test.
- Block 5: Stress test scenarios, looking at the scenarios' choices, such as horizons, physical and transition risks' aspects.
- Block 6: Data, analysing the availability of sources of the data in the internal climate risk stress test frameworks of the banks.

- Block 7: ICAAP[46], inclusion of the climate risk related stress test result in the ICAAP, with the final goal of understand how the capital allocated for credit risk will change in case possible climate-related problems.
- Block 8: Future plans regarding climate risk stress testing and interaction with other priorities, where banks need to provide information how they will improve their climate risk stress test in the future.
- Block 9: Involvement of the internal audit function in the climate risk stress test, specifying how the internal audit interacts with the stress test, with the final goal of spread the climate risks' culture in all banks' functions and activities.
- Block 10: Application of parent company climate risks stress test framework, that is applied to EU subsidiaries of non-EU institutions, and they need to explore their climate risk stress test framework.
- Block 11: Bottom-up stress test, methodological choices, and challenges to build bottom-up calculations, only for banks that will provide Module 3.

Module 1 has the aim to comprehend how climate change's risk is spread in all banks' functions, and how financial institutions are facing business model's changes that are needed to prevent possible financial crisis that will happen if financial players do not take action to be ready to face environmental issues, that will affect their portfolio positions.

8.2. MODULE 2: CLIMATE RISK METRICS

In 2022 climate risk stress test exercise, all banks are requested to provide a set of common climate-related metrics, describe in the Module 2 template, which focus on two climate risk metrics that provide insights into the exposure of institutions' income

[46]Internal Capital Adequacy Assessment Process.

to transition risk and to carbon-intensive industries, looking overall at the sustainability of banks' business model.

Financial institutions are asked to split their corporate exposures between 22 industries at the NACE two-digit, mapping the corporate counterparties to one single sector based on its principal activity[47]. Institutions are further required to provide information in an accompanying explanatory note on climate-related actions the bank has taken in the past to finance the green transition and, in addition, they can include forward-looking information on how their planning in the short and medium term contributes to financing green investments.

The two metrics identify by ECB are:

- Metric 1: Income of GHG intensive industries, where banks need to assess the business model sustainability based on interest income, fee, and commission income by NFC industry.
- Metric 2: Financed GHG emissions, looking at Scope 1, 2 and 3 emission data for banks' largest non-SME corporate counterparties per NACE sector.

[47]Activity that generates the highest share of the counterparty's revenue.

NACE industrial sectors	NACE industrial sector description
A01	Crop and animal production, hunting and related service activities
A02-A03	Forestry and logging; Fishing and aquaculture
B	Mining and quarrying
C10-C12	Manufacture of food products, beverages and tobacco products
C13-C18	Manufacture of textiles; Manufacture of wearing apparel; Manufacture of leather and related products; Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; Manufacture of paper and paper products; Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21-C22	Manufacture of basic pharmaceutical products and pharmaceutical preparations; Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24-C25	Manufacture of basic metals; Manufacture of fabricated metal products, except machinery and equipment
C26-C28	Manufacture of computer, electronic and optical products; Manufacture of electrical equipment; Manufacture of machinery and equipment not elsewhere classified
C29-C30	Manufacture of motor vehicles, trailers and semi-trailers; Manufacture of other transport equipment
C31-C33	Manufacture of furniture; Other manufacturing; Repair and installation of machinery and equipment
D	Electricity, gas, steam and air conditioning supply
E36-E39	Water collection, treatment and supply; Sewerage; Waste collection, treatment and disposal activities; Materials recovery; Remediation activities and other waste management services
F	Construction
G45-47	Wholesale and retail trade and repair of motor vehicles and motorcycles; Wholesale trade, except of motor vehicles and motorcycles; Retail trade, except of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52-H53	Warehousing and support activities for transportation; Postal and courier activities
L	Real estate activities

Figure 32: NACE two-digit list of industries

8.2.1. METRIC 1: INTEREST, FEE, AND COMMISSION INCOME FROM GREENHOUSE GAS INTENSIVE INDUSTRIES

The scope of Metric 1 is to assess the interest, fee, and commission income from non-financial corporation domiciliated in both EU and non-EU countries; income from EU counterparties should be filled in separately per EU countries, instead from non-EU corporates can be aggregated as non-EU, with the goal to cover at least 80% of gross interest and gross fee and commission income, with a maximum of five countries if the

threshold of 80% is not achieved. The reference period for the income and expenses data collection is the sum of the time-weighted notional instruments[48] that were on the bank balance sheet from 1 January 2021 to 31 December 2021.

With this metric, supervisors want to understand how much of the credit activities are sustainable in the future in case of environmental change and future natural disasters, analysing the percentage of income coming from interest, fee and commission generated by companies highly expose to carbon emission industries, and how these exposures are divided between countries. Financial stability of banks is strong correlated to credit market, and if some financial institutions' activities is concentrated only in high polluting sectors and, in the future, extreme events will happen, the instability coming from these banks will generate consequences to all financial system, that could end with a reduction of credit availability and possible crisis.

8.2.2. METRIC 2: FINANCED GREENHOUSE GAS EMISSIONS

The second metric wants to measure the exposure to carbon-intensive industries, analysing firm-by-firm position, and each bank is expected to provide the necessary data to calculate the weighted average GHG intensity metric, relying on Scope 1, 2 and 3 emissions of the counterparties, that will provide information for mapping direct and indirect emissions. Banks should report fifteen counterparties per NACE, but they can exclude industries that constitute less than 0.5% of the bank's total assets.

For each company, financial players need to collect several data, such as the counterparty's identification code, the same used in the reporting of Anacredit, the three-year average corporate revenues, the amount of bank exposures towards

[48]The time-weighted notional of an instrument is defined as the notional of the instrument times the fraction of the year in which the instrument was on the balance sheet.

counterparty, Scope 1, 2 and 3 emissions and, in addition, banks are required to provide exposures to counterparties as a percentage of total exposure per NACE sector. This analysis permits to understand at granular level each position of each bank, improving the results that supervisors should have used a top-down approach.

The inclusion of GHG emissions may lead to a potential double counting and so banks are asked to report the requested data separately for Scope 1, 2 and 3. For the purpose of this metric, counterparty's levels of emissions are calculated as follows:

$$Counterparty\ S1\ GHG\ intensity = \frac{Counterparty's\ Scope\ 1\ GHG\ emissions}{Counterparty's\ average\ revenues\ for\ last\ three\ years}$$

$$Counterparty\ S1S2\ GHG\ intensity = \frac{Counterparty's\ Scope\ 1+2\ GHG\ emissions}{Counterparty's\ average\ revenues\ for\ last\ three\ years}$$

$$Counterparty\ S1S2S3\ GHG\ intensity = \frac{Counterparty's\ Scope\ 1+2+3\ GHG\ emissions}{Counterparty's\ average\ revenues\ for\ last\ three\ years}$$

The financed Scope 1, 2 and 3 GHG emissions are then defined as follows:

$$\sum_{S1S2S3\ Targeted\ counterparties} \frac{S1S2S3\ GHG\ intensity\ x\ Bank's\ exposure\ to\ counterparty}{Bank's\ total\ exposure\ to\ S1S2S3\ targted\ counterparties}$$

The counterparty's revenues, as well as its Scope 1, 2 and 3 carbon emissions data, are taken by company's report, such as annual or sustainability reports; as a fall-back option, if Scope 3 is not available, banks can use proxies to estimate this emission, with a conservative view, and submitting an explanatory note to ECB with details of their calculations, such as data sources used and how their proxies were derived. Example of Scope 3 GHG emission proxies could be the average-sector based emissions, using industry average data, physical activity-based emissions, looking at company's energy production or consumption, and emission factors specific to primary data, or economic activity-based emissions, such as euro of revenues or euro of assets.

This metric permits to know each single position of banks, analysing each single counterparties, but some problems can rise: financial institutions need to rely on data contained in companies' reports, but these documents are relatively new and well-

known standards are not available, generating possible mistakes during the classification of each companies Scope 1, 2 and 3 carbon emission data. In this context, authorities' interventions are needed, to align all firms to the same level of data, with common measures and taxonomy. Another problem is connected to Scope 3 emissions, that are the most important parameter for banks: these emissions, that take into account also suppliers of each firm, could be difficult to identify for counterparties, that may work with entities of small size, generating missing data and, consequently, lower estimations compared to the real one.

8.3. MODULE 3: BOTTOM-UP STRESS TEST PROJECTIONS

The objective of Module 3 is to describe the methodology and requirements for the starting point data and projections that banks must provide for the bottom-up stress test exercise, targeting transition and physical risks.

For transition risk, ECB stress test take into account the global exposure of banks, analysing the effects of climate change in both short and long-term, with the adoption of a dynamic balance sheet for the latter situation; this introduction permits to bank to simulate the stress test in a more realistic way, due to the possibility of entry or exit from portfolio's position, in line with environmental context.

Physical risk, instead, is focused only on 2022, with the identification of two scenarios taken into account, defined as the drought and heat risk, and the flooding risk; the choice of select a short time period could be coherent with the non-linearity of possible physical damage, that would make difficult for banks to analyse and modify their portfolio, and also for authorities to understand if these changes could be realistic or not.

For both the situations, credit and market risk will be under analysis, looking at corporate loans, mortgages, bonds, and stocks issued by NFCs; ECB introduces also operational and reputational risk, coming from bad behaviour facing climate change, with the adoption of a qualitative questionnaire to assess them, that could include the incorporation of climate-related and environmental events, as well as issues in the banks' stress testing framework and mitigation actions.

<table>
<tr><th></th><th>Exposures</th><th>Scenario</th><th>Projections</th><th>Horizon</th><th>Credit risk</th><th>Market risk</th><th>Operational risk</th></tr>
<tr><td rowspan="4">Transition risk</td><td rowspan="4">Global</td><td rowspan="2">Short term stress</td><td>Baseline</td><td rowspan="2">Three years, from 2022 to 2024</td><td rowspan="2">Corporate loans + mortgages</td><td rowspan="2">Bonds + stocks issued by NFCs</td><td rowspan="6">Operational and reputational risks will be assessed via a qualitative questionnaire</td></tr>
<tr><td>Stress</td></tr>
<tr><td rowspan="2">Long term paths</td><td>Orderly</td><td rowspan="3">Thirty years, looking results in 2030, 2040 and 2050</td><td rowspan="3">Corporate loans + mortgages</td><td rowspan="3">-</td></tr>
<tr><td>Disorderly</td></tr>
<tr><td rowspan="2">Hot House</td></tr>
<tr><td rowspan="4">Physical risk</td><td rowspan="4">EU countries</td><td rowspan="2">Drought and heat risk</td><td>Baseline</td><td rowspan="2">One year (2022)</td><td rowspan="2">Corporate loans</td><td rowspan="4">1. All projections are based on static balance sheet assumptions
2. The parent company needs to be a NFC</td></tr>
<tr><td>Stress</td></tr>
<tr><td rowspan="2">Flood risk</td><td>Baseline</td><td rowspan="2">One year (2022)</td><td rowspan="2">Corporate loans + mortages</td></tr>
<tr><td>Stress</td></tr>
</table>

Figure 33: Scenarios under analysis in Module 3

8.3.1. TRANSITION RISK

ECB stress test covers banks' potential losses coming both from short and long-term transition risk scenarios, at global level. First, it would assess the vulnerability of the banking system in a three-year disorderly transition scenario triggered by a sharp increase in the price of carbon emissions. Second, it wants to assess the financial institutions' long-term strategies, looking at three different transition scenarios over

thirty years, analysing the results in 2030, 2040 and 2050; in this way, the stress test will provide information about good strategies to face climate change, also taking into account the adoption of a dynamic balance sheet.

ECB needs to develop new methodologies to understand how project banks' portfolio composition over thirty years; in fact, it is impossible to think that financial institutions are able to forecast future exposures in such a long time and, even if it should be plausible, the level of approximation will be too high, and the results will be misleading. In this context, financial players might decide to analysis the industrial plan of each counterparties in order to capture future actions that they will put in place, and project the portfolio's composition over the next three to five years; with this action, banks should be able to modify their exposures, and then forecast future possible damage related to credit losses over the timeframe defined by ECB, looking at result at 2030, 2040 and 2050. Using this dynamic balance sheet approach, European Central Bank will make a step forward compared to the current situation, where the "as is" portfolio's composition is considered as starting point, enabling banks to shift their assets allocation in the next years under analysis, and then project the final portfolio, assuming it as static, due to changes over a time horizon higher than the one of industrial plan should be not realistic and supervisors will have issues related to assessment of how much these actions should be plausible or not.

In a context where there will be a high level of uncertainty, Taxonomy will be crucial for credit exposures' projections: banks need to understand if the actions put in place by firms in their industrial plan will be really useful to reduce carbon emissions and go through eco-friendly activities; Taxonomy will play a fundamental role in the transition and in the future projections, helping financial institutions to understand which activities should be eligible as green and which will not, with the final aim of understanding the future risk of each counterparties connected to transition risks that they will face in the next decades, to better allocate the capital needed. Financial institutions, to analyse their positions, will also take into consideration activities that

nowadays are not considered as green, but in the future should be, in order to not exclude exposures that in the next years will reduce their carbon emissions, and also helping those companies to shift from high carbon emission activities to fewer polluting ones, with a consequence reduction in the risk profile associate to these exposures.

The credit risk exposures look at corporate loans and mortgages, and banks need to include as many countries as needed to cover at least 80% of their exposures, with a maximum of five countries if the percentage will not cover. Corporate exposures are split in three different portfolios, namely:

- Corporate exposures not secured by real estate property.
- Corporate exposures secured by real estate where the collateral is within the scope of the Energy Performance Certificate (EPC).
- Corporate exposures secured by real estate where the collateral is not within the scope of the Energy Performance Certificate (EPC).

Banks need to split these three kinds of exposures between the twenty-two industries identified by NACE two-digit level. Analysing collaterals within the scope of the EPC, financial institutions need also to break down their exposure by EPC rating that goes from A to G, but it should also be possible to develop an internal methodology when the classification is not available, comparing the current collateral with same building period of the property, size, or energy costs.

For what concern market risk exposures, the scope of evaluation is to calculate risks coming from corporate bonds and stocks in the trading book of banks, covering all equity and non-financial corporate bond positions under full or partial fair value measurement which are held with a trading intent; such as credit risk, financial institutions are asked to classify their securities holding by the same 22 NACE industries and, in addition, potential hedges (e.g., derivatives) directly connected to the equity and corporate bond positions need to be reported.

Looking at the short-term period, banks are asked to provide projections about credit risk for both the disorderly transition scenario and the baseline scenario, assuming a static balance sheet, replacing maturing exposures with loans and collaterals of similar credit quality and maturity over the three-year projection horizon 2022-2024. Financial institutions could use their internal models to assess how profitability and creditworthiness of counterparties will be affected by CO_2 price increase, considering both the direct impact of the shock on counterparties and the impact from the changes in the macro variables that accompany the carbon price shock, such as lower aggregate demand. For what concern market risk, banks need to calculate how the fair value of exposures will be affected by carbon price shock; the change in fair value needs to be broken down by risk driver, like equity, credit spread, interest rates assuming full transmission of the carbon price shock to their bond and equity positions, performing also fair value revaluation of associated hedging positions separately, describing banks' hedging strategies linked with trading securities vulnerable to carbon price shocks in their explanatory note.

Long term paths are the most meaningful part of the stress test, due to the importance that climate change will have in the long run for European banking sector, with the objective of encouraging banks to develop capabilities in projecting risk parameters under transition scenarios and developing new strategies regarding the business mix over the full transition cycle, assuming a dynamic balance sheet view.

The exercise considers the three scenarios defined by NGFS, the same of the first economy-wide stress test, spanning from the present day up to 2050:

- The orderly scenario assumes a smooth reduction in CO_2 emissions able to achieve the carbon emission goals by 2050.
- The disorderly one assumes that the decrease in carbon emissions does not decrease quickly enough until 2030, triggering a disorderly transition in the following years able to achieve emission targets by 2050.

- The hot house world scenario assumes no reduction of CO_2 emissions with huge increase in physical risks, resulting in GDP losses.

Banks are asked to project their mortgages disaggregated by EPC and corporate exposures divided by industry for reference dates at ten-year interval (2030, 2040 and 2050), with two main differences with the previous short term view: first, banks could change their portfolio, according to the dynamic balance sheet assumption, permitting a more realistic view and results, even if authorities need to understand if the actions put in place by banks should be plausible or not; second, the accuracy of credit risk projections will be lower due to a higher time frame and more assumptions based on portfolio rebalancing, with the objective of obtain detailed insights about the resilience of banks' business models and their adaptability in different long-term transition scenarios.

For the purpose of the stress test, ECB considers credits in stage 1 and stage 2 as performing, and stage 3 as non-performing, permitting banks to change and adapt their balance sheet according the two complementary categories: bank-specific strategy on the one hand, and bank's business environmental linked to the scenarios on the other hand.

For the first one, financial institutions may consider the willingness to maintain a long-term relationship with existing clients and support their transition, as well as selecting specific creditor taking into account reputational risk; moreover, also the market position of banks within economic sector could play a relevant role, since if a financial institution is a key financing actor for a given economic activity, its ability to exit might be limited, even if it is one of the most polluting.

Looking business environment, when performing the reallocation of exposures by industry within the corporate portfolio, banks can consider sectoral developments related to GHG emissions, with the final aim of open or close position based on evolution of specific market.

Financial players should also specify if their changes in exposure to an industrial sector or EPC label is due to balance sheet growth or reallocation; in the former case, in fact, the exposure of one sector is assumed to be constant, without reallocation, if it is not declared by the financial institution.

Banks are asked to report the main parameters for each scenario and for each timestep, including the number of sectors where banks increase or decrease their exposures, the average growth of associated exposures, and, in relation to exposures secured by real estate, the EPC rating for corporates and mortgages, and the average EPC reallocation. For what concern credit risk, financial institutions need also to provide projection for point-in-time PD, point-in-time LGD and the stock of provisions for performing and non-performing exposures for 2030, 2040 and 2050.

Compared to the previous stress test, the introduction of dynamic balance sheet assumption permits to have a better understanding of the future stability of financial system, even if authorities have the crucial role to understand how much plausible should be the actions that financial players decide to put in place regarding the reallocation of their portfolio.

8.3.2. PHYSICAL RISK

For the purpose of the 2022 climate risk stress test exercise, the assessment of physical risk takes into account two main extreme events: large flood, since river flooding has been a major source of physical risk in Europe, and severe drought and heatwave, that will affect several sectors, such as transport infrastructure and agriculture. ECB decides that banks need to focus only on direct impact of this risk on the credit one, without taking into account second-round effects linked to losses borne by insurance companies.

The analysis of physical risk will focus only on short term, with a one-year projection horizon; unlike in the transition risk exercises, only EU counterparties are in the scope of the analysis, covering at least 80% of the corporate exposure, with a maximum number of five countries if the threshold is not achieved; as transition risk, institutions are asked to classify their credit exposure to counterparties broken down by NACE sector at the two-digit level at 31st December 2021.

In the drought and heat scenario, the entire EU will be hit by a heatwave on 1st January 2022 which results in output losses for vulnerable industries. Banks, assuming static balance sheet over this horizon, are asked to provide one-year-ahead projections for exposure, credit parameters and stock of provisions as at the end of 2022.

Floods could cause severe damage to buildings, thereby reducing the value of properties that banks use as collateral for loans: as the main transmission channel works through changes in the value of the underlying assets, the stress test is focused on mortgage exposures to households and to firms that are secured by real estate, with a result that only loans with immobilize properties as collateral are in the scope of analysis. Banks are asked to classify their credit exposures to these counterparties in accordance to NUTS map, identifying four levels of risk: no risk, low risk, medium risk, and high-risk areas; each position must than identify according to the country and to the flood risk category. In order to keep the exercise manageable, banks can assume that, in the same NUTS region, the level of PD and LGD are the same for each counterparty, and the other economic variables, such as GDP growth and interest rate, will be unaffected by the flood.

For both heatwave and flood risk, banks need to made calculations bade on baseline scenario (i.e., no risk) and stress scenario, assuming static balance sheet for the one-year horizon. The result of this section provides a snapshot of the overall banks' exposure about their collateral, helping them to improve their portfolio, analysing not only the creditworthiness of each counterparty, but also where the property is located

and how much the risk associate to a specific area is high, in order to prevent possible losses and increase in the probability of default coming from natural disaster.

8.3.3. OPERATIONAL AND REPUTATIONAL RISK

Climate-related and environmental events could also increase operational and reputation risks, with financial losses coming from legal claims (i.e., conduct risk) that derive from climate change, impaired business continuity due to extreme weather events such as droughts and flood, and reputational losses result from the financing of not-eco-friendly activities made by counterparties; a negative financial impact could arise where there are controverses about product owing to underlying investments with an adverse environmental impact. Furthermore, also banks' assets could be affected by environmental events, that might generate operational losses. Moreover, providing finance to companies with significant polluting activities can be a driver of reputational risk for the institutions.

9. DYNAMIC BALANCE SHEET

ECB stress tests generally start to analyse the current portfolio's composition of each financial institution, and project it on the future three years, under different adverse scenarios; in this context, the static balance sheet assumption[49] could be useful to understand impacts of external events on banks' financial stability, due to the short time period under analysis; in spite of ensuring simplicity in the exercise, this assumption means basically that the balance sheets of participating financial institutions are assumed to remain constant over the stress test time horizon, without the possibility of selling certain portfolios or part of their activities, or adapting the business model to new situations, that is obviously unrealistic and it does not provide information and does not take into consideration future strategies and actions that banks should put in place to manage possible problems related to solvency, liquidity or profitability connected to changes in the environmental conditions. Additionally, a time horizon of three years is insufficient to comprehend the real consequences of transition and physical risks, due to their characteristics that will manifest in a longer time frame. On the other hand, supervisors do not have to judge about how realistic the assumptions are when new actions are put in place, facilitating the exercise with a reduction of the complexity, to the detriment of realism.

Taking into account climate change, if Central Bank continues to use a static view, it will be impossible to predict the correct stability of financial institutions; in fact, the time horizon taken into consideration in the economy-wide stress test is about thirty years, and it is not plausible to think banks never change their portfolio's allocation from the current one to 2050: allowing financial institutions to use a dynamic balance sheet view gives banks room to account of their individual circumstances and add incentive to each financial player to invest in their risk management.

[49]Financial Stability Institute (November 2018).

The dynamic balance sheet approach[50] represents a tool able to capture changes in the portfolio's allocation, permitting to understand the impact of extreme events in a context where financial institutions could modify their exposures and analyse all possible consequences related to both transition and physical risks and energy transition put in place by highest pollution companies, enabling banks to redefine their portfolio's composition, reinforcing the capability to predict future capitals' needs and overcoming the limitation of a short time period under analysis as today in the capital adequacy stress test. In fact, due to the nature of a dynamic balance sheet assumption, size, maturity and product mix are allowed to vary during the time horizon of the exercise, in a way consistent with the macro scenario, allowing incorporation of management decisions during all the time frame, providing an insightful forward-looking view of foreseeable developments at bank level; however, this greater realism will be in contrast with the possibility of supervisors to understand and scrutiny if these actions that will be put in place could be realistic or not.

In this sense, ECB published the Single Supervisory Mechanism Stress Test in which the static balance sheet assumption was relaxed: in this document, European Central Bank describes a uniform methodology for conduction a bottom-up exercise able to identify the current and future stability of European banks. Moving from a top-down to a bottom-up approach, each single bank needs to develop its projections based on customized model, set on technical constraints imposed by authorities, such as caps of floors for specific indicators. Dynamic balance sheet assumption is included in the analysis of long-term transition paths that consider a time horizon of thirty years, looking at possible changes in credit portfolio allocations in case of orderly, disorderly, and hot house world scenario.

This first introduction in ECB stress test shows how Central Bank understood the importance of analyse the consequences in the long term, and how the static balance

[50]Deutsche Bundesbank (2017).

sheet limits this forecast: including this new perspective helps both financial institutions and supervisors to have a better picture of banks' financial stability, showing not only the current situation but also future damages and actions against climate risk. On the other hand, financial players need to make realistic assumptions that could not be easy to control by authorities, considering a time horizon of thirty years; in fact, European Central Bank needs to be aware that the results from each single bank should be heterogeneous across each single player, mainly due to different strategies that should be put in place to face the same problem that will happen in the future.

The changes connected to the dynamic balance sheet assumption could also be seen as the possibility of banks to help companies to shift from polluting activities to eco-friendly one. In this context, financial institutions will have a double way to reduce their risk profile connected to climate change: on one hand, they could shift their exposure between sectors, from highly exposure to climate-related events to greener one; on the other hand, they could help companies to reduce their risk profile, financing their activities connected to the movement to less polluting technologies, reducing the transition risk linked to them, but also sustaining projects with the final aim to protect current properties against extreme weather events, decreasing the expected losses that banks should see in case of environmental change connected to physical risk. In this perspective, the possibility that highest emitting firms will be excluded from the financial system is reduced, and banks will play a crucial role to permit to all companies to move to eco-friendly assets.

In addition, the current feedback loop of analysis, based on firm's sector, need to be enriched with a further layer of banks' exposure classification, looking also at companies' carbon footprint and exposure to physical risks. Firms with a higher carbon emission should suffer more mark-to-market losses under different scenarios, with the consequence that financial players mostly exposed to these companies would

experience a higher reduction in profitability, that will influence a further deterioration of the macroeconomic conditions, also generating instability in the financial system.

To be ready to analyse company-by-company situation, several challenges will rise, starting from the definitions of common standards for the disclosure of Scope 1, 2, and 3 emissions. The Corporate Climate Responsibility Monitor 2022 assess twenty-five major companies in the world to define four good practices that should help to cover the information gap and transparency:

- Tracking and disclosure of emissions, that includes the disclosure of all GHG emissions on annual basis, and a representation of historical data to compare the evolution of the transition; the study shows how only seven out of twenty-five companies declare full details on all Scope 3 emissions sources, and how this information needs to be integrated in the companies' disclosure to the market, also to facilitate the interpretation of data by financial institutions.
- Setting specific and substantiated targets, with the aim of explicitly state companies' target about Scope 1, 2, and 3, setting both short and long-term target with the goal of monitor the progresses of each action put in place, with the first target on a maximum of five years that requires immediate actions and accountability.
- Reducing own emissions, that includes the implementation of decarbonization measures, with the definition of specific target to support the transition; none of the twenty-five firms assessed in the report provide information on how they will reduce their emissions. Upstream and downstream value chain emission account of average for 87% for all the companies taken into consideration, but firms have no plans about how they will address the reduction of these emissions.
- Climate contributions and offsetting, where the first one is defined as the financial support provided by a company to support climate change action beyond the company's own value chain, without claiming to neutralise its own emissions that is considered more effective compared to the offsetting activities,

that are characterised by uncertainty in the real impacts for emissions' neutralizations.

These four actions have the aim to increase the transparency and the integrity in the companies' disclosure, but also reduce greenwashing practices put in place by firms that declare themselves as green but, in reality, their actions do not have a real impact on their GHG emissions.

	Good practice: Transparency	Good practice: Integrity
Tracking and disclosure emissions	Low: 6/25	Low: 6/25
Setting specific and substantiated targets	Reasonable: 12/25	Low: 6/25
Reducing own emissions	Very low: 3/25	Very low: 1/25
Climate contributions and offsetting	Very low: 1/25	Very low: 0/25

Figure 34: Overview of good practices

As shown in Figure 34, firms' good practices are most of the case low or very low: in this scenario, banks will have high difficulties to understand the level of commitment of companies to greener transition, and the screening process to understand if a company is green or not will become more complicated. The ability of financial institutions to predict especially transition risk will play a fundamental role for what concern the positive result in the assessment process to give the loans: if companies do not show effectively how they will move from a GHG high emissions' activities to greener technologies, banks should not have sufficient information to understand if these firms will survive to possible transition risks, with the consequence of credit crunch, or an increase in the overall risk portfolio for financial players.

9.1. CHANGE IN THE TIME HORIZON

The two main innovations connected to the introduction of a dynamic balance sheet approach are the change in the time horizon, that moves from three to thirty years, with intermediate steps where supervisors could analyse halfway results, and the reference date that authorities need to take into consideration to start their projections related to the capital adequacy.

For what concerns the first one, the shift from three to thirty years is mandatory: taking into account transition and physical risks, but also the ability of banks to finance green projects to firms in order to help them to move towards a greener business model, need a suitable time horizon able to capture all possible consequences that will not manifest in the short term. In this context, banks need to integrate their credit risk appetite (CRA), based on probability of default and loss given default, with new parameters connected to climate-related events, classifying each single NACE sector with a coding that describes how much it should be influenced by environmental issues. This result will be reached only with a deep integration between the risk management activities and the scientific works, that will permit to understand future possible consequences on assets located in all geographic areas, with the correspond level of risk.

In addition, a common methodology must be defined in order to have mathematical standards in the CO_2 emission calculations and in the reports' format produced by companies: in this perspective, financial institutions need a high level of details from firms, where the long-term goals will be both qualitative but also quantitative, in order to permit to the banks to monitor all the intermediate steps necessary to reach the final results, moving from polluting to eco-friendly activities. Financial institutions need not only to capture all future consequences regarding the increase in the probability of defaults in such a long time horizon, but also they need to develop new models able to provide insights about how they could change portfolio's composition across sectors,

in order to prevent and reduce possible losses coming from climate-related events connected to those companies that are not ready to face environmental issues.

9.2. CHANGE IN THE REFERENCE DATE

The second innovation could be seen in the reference date taken into account by authorities to project the portfolio composition over the thirty years. Nowadays, the stress tests take into consideration the balance sheet composition on December 31st of the year before, meanwhile the date of results' publication of stress testing activities is July 30th: as it is possible to understand, the valuations do not comprehend all the activities put in place by financial institutions from the delivery date of the balance sheet composition to the valuation date. This aspect will be even more relevant if a dynamic approach will be considered: in fact, one of the major challenges that could rise is to understand after how much period banks need to stop their projections about changes in the portfolio's allocation and consider the final composition as "frozen", in order to project it along the remaining years taken into consideration.

Whit this premise, a reasonable period that banks should have to change their assets allocation could be from three to five years, the usual time period that companies' industrial plan takes into account: in this way, financial institutions may analyse each firms' objective and understand how much it could be plausible or not, in order to adapt their exposure to each counterparty. During this timeframe, financial player should integrate different objectives coming from different counterparties, in order to comprehend which ones will be the most plausible, with a higher probability of success, and project the portfolio's composition based on companies' goal, described in their sustainability report.

In this situation, the main challenge that should rise is the problem connected to greenwashing, where firms could declare in their future actions to move from eco-

friendly activities, without put in place real steps to reach their objectives; in this context, the need of a standard methodology for what concern both quantitative and qualitative parameters will be fundamental, in order to permit banks to compare one company to another, and also understand if the goals should be reached or not. Moreover, financial players, when they will provide credit to those companies, should put in place a step up interest rate condition, where the increase in the coupon depends directly on environmental goals' achievement: in this way, companies are forced to declare objective that they should be able to achieve with higher probability, and the possibility to publish unrealistic goal will drop.

10. CASE STUDY: FLOODING RISK IN ITALY

The case study considers a portion of the mortgage portfolio of the biggest Italian bank, Intesa Sanpaolo (ISP), analysing how the increase in the flooding risk will modified the expected probability of default and loss given default in 2040, considering exposures in 85 out of 110 Italian provinces, and taking into account two different scenarios, RCP 6.0, and RCP 8.5, compared with a base case, RCP 4.5.

To run this analysis on its portfolio, ISP used the European Flood Model of RMS, a methodology commonly used by governments and financial institutions to quantify and manage their exposure to extreme events; RMS modelling framework consists in five modules:

- Stochastic module, that permits to simulate events for specific peril; in this analysis, the model allows to analyse the consequences of a full range of possible severities of floods that could impact Europe. Each event is assigned an annual probability based on its characteristic, with the most severe event having the lower probability of occurrence.
- Hazard module, where an event is simulated and the model permits to understand the consequences on this event on the peril under analysis, calculating the hazard footprint associated with each possible situation.
- Exposure module, that represents a database extraction about assets at risk in a specific geographic area; the exposure database contains information on the location, the value, and the building characteristics of each asset, permitting, with an overlay of hazard module outcome, to understand the possible impact of extreme events on specific assets in specific locations.
- Vulnerability module, which varies by peril under analysis and physical attributes of an asset.
- Financial module, that permits to calculate the financial loss associate at each stochastic event and each portfolio's position; losses are then aggregated across

all assets to have a picture of overall exposure, taking also into account any applicable protections that might be in place or under consideration, to reduce possible losses coming from physical risks.

The first two modules can be used to have a view on how frequently a location is to be impacted by hazard events, instead, the other three modules could assess the frequency and the severity of the economic impact coming from a specific peril, like the flooding risk considered in this simulation.

10.1. SCENARIOS

The RMS model was applied to both RCP 6.0 and RCP 8.5 scenarios, that were compared with the RCP 4.5 one, considered as baseline.

	Temperature increase 2046-2065 (compared to 1986-2005)	Global sea level increase 2046-2065 (compared to 1986-2005)	Source of energy generation
RCP 4.5	1.4 °C	0.26 metres	Moderate use of renewable energy
RCP 6.0	1.3 °C	0.25 metres	Renewable and polluting activities
RCP 8.5	2.0 °C	0.30 metres	Coal-fired power

Figure 35: Scenarios under analysis

RCP 4.5 is represented as the most plausible scenario that will occur in the future if no significant policies will be put in place by authorities. It is characterised by a medium effort by actors in the economy to prevent a huge rise in temperature, that could be projected to be, between 2046 and 2065, higher of 1.4 °C compared to the average increase between 1986 and 2005[51]. This situation can be justified by a moderate use of

[51] https://ar5-syr.ipcc.ch/topic_futurechanges.php

renewable energy and a good mix of transports, including both polluting ones and not, but without the introduction of new technologies, such as the carbon emission capture tools. In this scenario, the extreme weather event probability is considered to increase in a moderate way, and the sea level, analysed in the same time frame as temperature growth, is expected to rise of 0.26 metres.

RCP 6.0 is an intermediate scenario where the energy generation will be composed by both renewable and not activities, with a temperature increase of 1.3 °C and sea level rise of 0.25 metres. The results are pretty similar to the baseline scenario, with the only difference in the energy generation: in this situation, in fact, the polluting activities play a relevant role in the energy production, with a transition to green technologies slower compared to RCP 4.5.

RCP 8.5 represents instead the most extreme situation, characterised by coal-fired power as the primary source of energy generation, that will cause a temperature increase of 2.0 °C between 2046 and 2065, and a global mean sea level rise of 0.30 metres in the same period. This represents the most adverse scenario, where no actions to facilitate the transition to eco-friendly activities are put in place, with a consequent increase in temperature and sea level more than twenty percent compared to the intermediate scenario.

The three scenarios highlight how important a proactive approach is, moving from high technologies carbon emissions to green ones. The increase of the global sea level represents one of the most critical variable for the flooding risk taken in consideration; the value of the collateral for mortgages could decrease rapidly in case of extreme events, and financial institutions need to consider these scenarios in their risk assessment framework, due to it will become more relevant year over year, and the ability of banks to forecast and prevent such risks will play a crucial role in the following years.

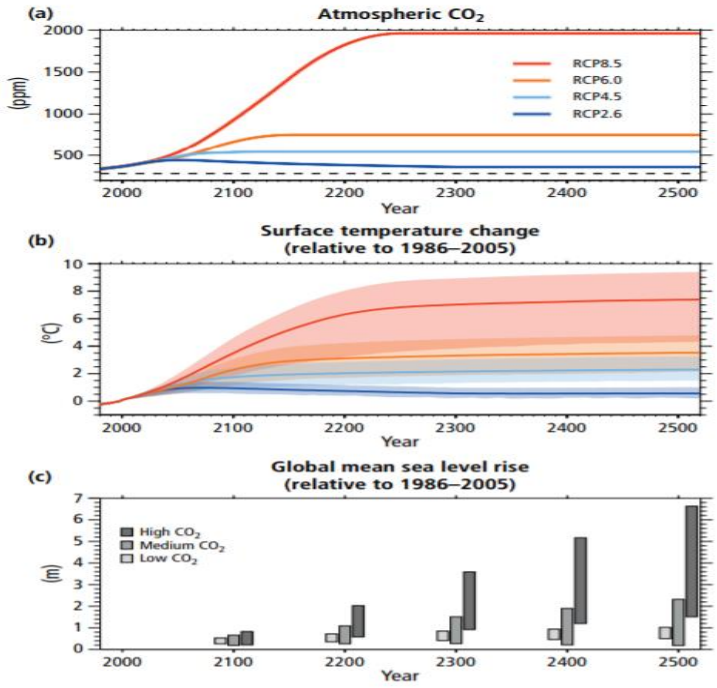

Figure 36: Consequences of RCP scenarios on atmospheric carbon dioxide, temperature, and sea level rise[52]

10.2. CHANGE IN CAPITAL ALLOCATION

The result of the simulation shows how the impacts on initial PDs and LGDs can substantially vary from an increase of 4% to 39% with respect to the initial values, and with a rise in the average annual loss (AAL) in a range between 6% in case of RCP 6.0 scenario in Milan and Turin, to 78% looking at RCP 8.5 situation in Catania.

Positions sorted by PDs	Initial Average PD	Stressed PD	Initial Average LGD	Stressed LGD	Stressed PD (x-times)	Stressed LGD (x-times)
PD <= 0,1%	0,04%	0,05%	4,98%	5,63%	1,19x	1,13x
0,1% < PD <= 0,5%	0,24%	0,30%	10,50%	14,64%	1,23x	1,39x
0,5% < PD <= 1%	0,68%	0,85%	10,56%	12,22%	1,25x	1,16x
1% < PD <= 3%	1,75%	1,92%	10,67%	11,54%	1,09x	1,08x
PD > 3%	6,25%	6,53%	12,86%	14,09%	1,04x	1,1x

Figure 37: Analysis of stressed PD and LGD, processing on ISP data

[52]IPCC (2014).

Province	Average Annual Loss (EURO) Gross Loss				
	Base View	R60_2040	R85_2040	Change R60_2040	Change R85_2040
	77.401	**88.165**	**96.101**	14%	24%
Roma	228,18	306,93	373,42	35%	64%
Milano	612,16	647,95	667,10	6%	9%
Napoli	421,09	550,56	652,12	31%	55%
Torino	223,70	236,50	242,53	6%	8%
Genova	7,43	9,56	12,19	29%	64%
Bologna	11.206,81	12.366,98	13.125,89	10%	17%
Firenze	23.658,00	25.739,75	27.098,80	9%	15%
Bari	798,44	883,96	979,61	11%	23%
Catania	0,14	0,21	0,25	45%	78%
Verona	1.413,16	1.559,92	1.683,84	10%	19%
Venezia	115,42	123,83	124,66	7%	8%
Other	38.716,00	45.739,05	51.140,88	18%	32%

Figure 38: Average annual loss, processing on ISP data

Data demonstrates how significant will be the impact of flooding risk on mortgage portfolio: the average annual loss will be 24% higher in case of most adverse scenario, and it drops to 14% in the RCP 6.0 situation. Figure 38 shows how heterogenous the situation is, and demonstrate that banks need to develop new tools in order to capture the magnitude of extreme events on their portfolio; compared to the past, financial institutions need to analyse not only the financial situation of a customer, if it is able to payback interests and principal, but also the location of the properties, which could influence the spread on mortgage, or will provoke an additional collateral request during the underwriting process.

The increase in the probability of default and loss given default will also generate effects on the capital needed by the banks to respect Basel III requests: in fact, for what concern credit risk, financial institutions need to be aligned to Pillar I that wants a tier 1 plus tier 2 capital equal or higher than 8% of the Risk Weighted Assets (RWA), and common equity tier 1 with a minimum level of 4.5% of RWA.

The capital needed by bank for a specific position can be calculated as follow:

$$Capital\ needed = EAD\ x\ LGD\ x\ (WCDR - PD)\ x\ MA$$

where each component represents:

- Exposure at default (EAD), that is the amount of the mortgage.
- Loss given default (LGD), defined as the total losses bank could have if there will be a default, that is the percentage of EAD not covered by collateral.
- Worst-case default rate (WCDR), that represents, with 99.9% of confidential level, the maximum loss that bank could have, function of the probability of default.
- Probability of default (PD), that shows how bigger is the possibility that counterparty will not payback the mortgage.
- Effective maturity (MA), that represents the duration of each position; higher it is, more capital is needed.

Analysing the formula and combing it with the results of the stress test, it is clear that an increase in the probability of extreme events, with direct consequences on PD and LGD, could generate an increase in the capitalization of banks; financial institutions need to become more efficient in the portfolio's allocation in order to prevent this situation, permitting them to not increase the amount of equity needed.

A first approach could be done acting on the loss given default, that could be defined as follow:

$$LGD = 1 - RR$$

LGD is negative correlated to recovery rate (RR); banks need to ask for more guarantees for positions where the probability of extreme events is higher and where it should increase in the future, in order to maintain a loss given default constant and not generate a capital call to stay in the limits imposed by Basel III regulation. In this sense, financial institutions could ask as collateral not only the property that mortgage finances, but also additional collaterals that banks could use in case of extreme events to maintain a lower LGD.

The second element that should be stressed is the probability of default and the worst-case default rate. These two parameters depend on the creditworthiness of the counterparties, and its ability to payback interests and principal in the future.

WCDR is defined as follow, with a confidential level of 99.9%:

$$WCDR = N\left[\frac{N^{-1}(PD) + \sqrt{p}\, x\, N^{-1}(0.999)}{\sqrt{1-p}}\right]$$

Worst-case default rate is function of probability of default and correlation between portfolio's positions (p), that, for retail positions under analysis, is equal to:

$$p = 0.03 + 0.13\, x\, e^{-35\, x\, PD}$$

The capital needed is direct functioning of (WCDR – PD), so banks need to maintain this term as constant as possible to not raise new capital from the market. The increase in the probability of default in the portfolio under analysis shows how financial institutions' positions could see an increase of PD of 25% in case of stress scenarios; in this situation, the ability of banks to select counterparties with a high credit scoring and located in areas where the flooding risk is low will play a relevant role. It could be also the case that, during the KYC[53] agreement, financial institutions need to analyse deeper the sources of income of the clients, which might be influenced by extreme events, reducing their creditworthiness and consequently generate an increase in the probability of default.

10.3. CHANGE IN ASSETS ALLOCATION

Another point under analysis is the correlation between positions: as shows in Figure 38, the location of each mortgage could change drastically the consequences of extreme

[53]Know Your Customer.

events on the average annual losses, moving specific positions in specific location to a red credit risk appetite; in this situation, also the geographic area in which the properties are located will play a crucial role to give to the client a positive or negative feedback on mortgages' request.

In this context, a dynamic balance sheet approach should be put in place in order to understand how ISP could modify its exposures to reduce the specific risk associate to specific geographic areas; in fact, considering the mortgages' portfolio under analysis, it is difficult to think that the bank could oblige counterparties to make investments to reduce the possible consequences of physical damages on the properties or to sign policies against flooding risk if not mandatory, with the result that the only possible way to reduce the exposure to physical risk is to shift the assets allocation, moving from areas where the risks are high to zones where the possibly of extreme weather events is lower.

Moreover, in areas like Rome, where the average annual losses are expected to increase of 64% at the end of time horizon, securitization process, with mortgage-backed securities (MBS), should be taken into consideration, with a consequent reduction of the specific risk associate to geographic area, and lower capital request by authorities. This solution should be also difficult to put in place, considering that the amount of the exposures connected to a red CRA will be difficulty absorbed by the market, with a direct consequence that this solution could not easily put in place, or could be with only a small portion of the overall mortgage's portfolio.

Extending this analysis on the overall credit portfolio, it is clear how financial institutions need to integrate their credit risk appetite model with parameters connected to climate risk's exposures of each counterparty. If the scope of analysis is shifted from an individual mortgages' portfolio to firms' lending activities, a dynamic balance sheet approach could help to prevent possible future capital requests: taking into account companies' exposures, banks should help firms to make investments in order to reduce the exposure of their assets to climate-related events, with the consequence that

probability of default will not increase, and the overall capital needed will remain constant; otherwise, if non-financial companies will not take actions to prevent these risks, financial players need to shift their exposures to other counterparties with a lower risk profile, or accept a higher capital needed to maintain their portfolio's positions, with a consequent reduction in the overall profitability.

11. BENEFITS FROM GREEN ECONOMY AND CONSEQUENCES ON BANKS' ACTIVITIES

European Central Bank understood the importance of climate change since November 2020, when it published its thirteen expectations that banks need to put in place to be ready to face new challenges related to extreme weather events. From this starting point, with the publication of the economy-wide climate stress test and Single Supervisory Mechanism 2022, the level of analysis went deeper, with the final goal of modify the current activities of financial institutions and introduce new standards in the stress test practices, in order to be able to face climate change issues; these updates should be put in place thanks to the recognition, at global level, of transition and physical risks that all actors in the market, from financial player to non-financial companies, will face in the future. Combining studies coming from the scientific communities, with the initiative at European level, such as the EU Taxonomy to better identify eligible activities to prevent extreme weather events, banks are able to analyse future adverse scenarios and forecast how their activities and capitalization will change in all possible situations.

The results of the ECB's economy-wide stress climate stress test first show how the short-term costs of transition pale in comparison with the costs associate to no actions in the medium to long term, due to benefit coming from the early adoption of green technologies able to reduce possible physical risks characterised by a higher level of magnitude compared to the transition ones. The studies also show how the effects of climate change, if not mitigated, will be concentrated in certain specific areas and sectors: companies locate in geographic areas that are most exposed to physical risks will face a decline in their creditworthiness as a consequence of more severe natural disaster; specific sectors, such as mining and electricity, will face more costs associate to their current activities, mainly due to carbon taxes needed to reach Paris Agreement

target, with a substantial increase in the probability of default and decrease in the level of profitability.

Additionally, physical risks become increasingly higher over time due to their non-linear function, and due to their irreversible nature. The projections of firms' and banks' expected probability of default are mostly connected to damages coming from natural disasters; the impact on financial institutions' expected losses will grow if no actions do not put in place to mitigate climate issues and to move through eco-friendly activities. Moreover, the highest expected losses on loans that banks are facing is connected to properties located in distress geographic areas with a low level of collaterals' protections compared to the high exposure to physical risk.

In this context, financial players need to change their credit activities, adapting and updating their business model and their risk appetite framework taking into account variables connected to climate change that before were not considered: as in the last decades, the key parameter was the creditworthiness of counterparties, nowadays it must be integrated by considerations regarding the sustainability of their business model, and how much their activities are exposed to climate issues.

In this perspective, also well-defined stress tests used by European Central Bank need to be updated; in fact, the static balance sheet view that is always used during stress tests is not able to capture possible consequences and analyse possible scenarios that could drastically affect banks' financial stability. Due to the highest importance of climate change, ECB needs to shift to a dynamic balance sheet approach, where financial players are able to project their assets allocation in the future based on scenarios coming from the scientific consensus, in a way that permits to reach results more realistic compared to the ones that will be reach if the current portfolio will be projected in the future without the possibility to make changes connected to the evolution of the global context.

Overall, the future path is defined: financial institutions need to develop new tools able to capture all possible consequences coming from climate issues and how they will impact their financial stability and level of capitalization; authorities need to adapt their models in order to be ready to have a more flexible approach, able to make stress tests activities more realistic as possible; non-financial companies need to start the transition from polluting activities to eco-friendly ones, in order to meet the net-zero and to reduce possible consequences on their profitability and probability of default. The collaboration between these three actors, with the studies coming from the scientific communities, will be crucial to defined how the global situation will evolve in the future, and only if all entities will make the same effort to reach the same goals, the net-zero, a reduction in the probability of extreme weather events will meet.

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