Louvain School of Management

How to integrate climate risk into the risk taxonomy and link it to the regulatory capital?

Author: Maxime Picron
Supervisor: Ruben Olieslagers
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I. INTRODUCTION

According to the "Climate Change" IPCC report (2021), the average global temperature has risen by 1 degree since the end of the 19th century and continues to increase at an unprecedented rate. In fact, scenarios predict that despite not producing GHG emissions, the temperature will still slightly become warmer and will not cool down until at least 2060. Consequently, the financial damage associated with climate change will inevitably escalate as global warming grows.

An essential element to assess this crisis relies on the heart of our economic system: financial institutions. These entities play an indispensable role in steering societies towards an economy that is financially resilient and aims a more sustainable society in order to limit or even cut back this warming.

As a starting point, this paper will go through the means of integrating climate risk into the current banking framework, analyzing the characteristics of climate risk but also its impact on banks' risk management structure. It will then present how it can be linked with regulatory capital, by exploring current frameworks and propositions from relevant sources. The question to be answered will therefore be "*How to integrate climate risk into the risk taxonomy and link it to the regulatory capital?*".

We will then explore empirically, in the second part, the impact on bank capital of integrating climate risk into the credit risk of banks investing in corporates, by calibrating the Asymptotic Single Risk Factor (ASRF) model. Following our research, we will present, analyze and discuss the results obtained, to finally give the conclusion and the limits of the dissertation.

II. LITERATURE REVIEW

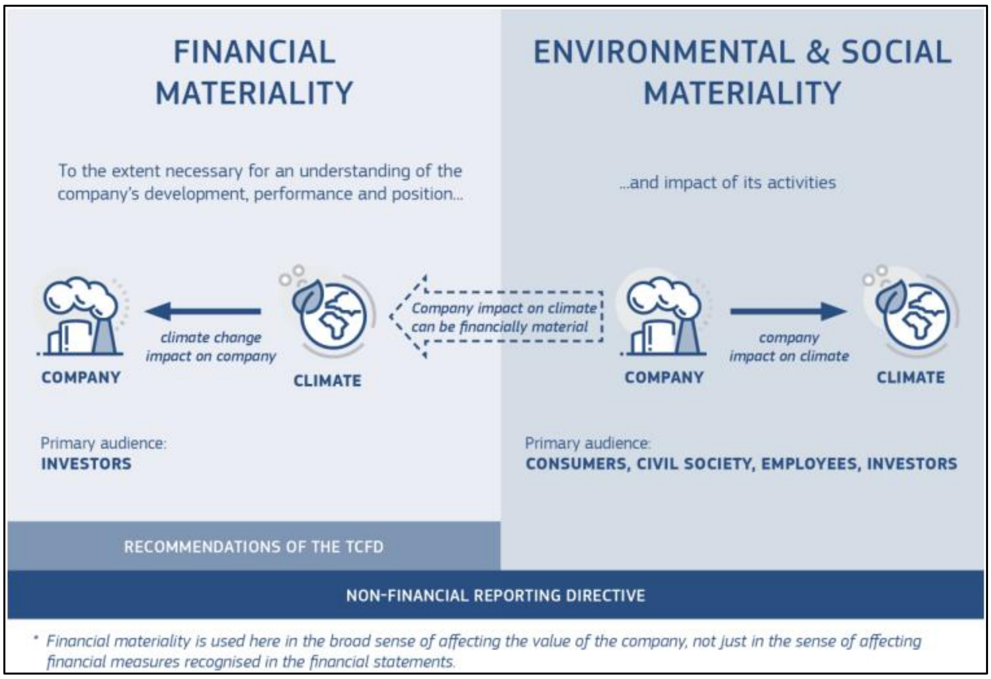
1. Introduction

It is tempting to put the responsibility for managing climate risk back on the market itself, as it should naturally respond to the needs of the economy. According to the well-known theory of market efficiency (Fama, 1970), this postulates that the markets, incorporate and pass on all the relevant information in their prices. From this, we could assume that climate risks, as relevant information, would be automatically taken into account.

However, this approach was first criticised for its assumption of perfect markets (Akerlof, 1970; Stiglitz, 2002) and shown to be obsolete when it came to taking climate risk into account. According to a study by the Bank for International Settlements (Eren et al., 2022), financial markets tend to underestimate climate risks, leading to an accumulation of these risks in the financial system. This has led to some authors such as Stern (2007), in his book “The Economics of Climate Change” and Da Silva (2019) in “Research on climate-related risks and financial stability: An "epistemological break"?” to suggest the need for taking a more active role in the management of these risks by regulators, financial supervisors and central banks.

According to Kristalina Georgieva, CEO of the World Bank and pointed by Stern (2007), climate risk adaptation and mitigation are two sides of the same coin. Indeed they consider that adaptation and mitigation are not independent dimensions, but that the success of mitigation will determine the scale required for adaptation. This indeed follows the vision of the Non-Financial Reporting Directive, according to European Commission (2019a), giving this double materiality perspective.

Figure 1: The double materiality perspective[1]



This concept introduces the idea of a 'feedback loop', between climate change and the financial system, which differs from the TCFD approach, which focuses solely on the financial perspective. This principle describes the cycle in which the climate, through its changes, impact the company which, through its decisions, can in turn influence the climate. The International Monetary Fund's publication points out that adopting policies in favour of a low-carbon economy could reduce the financial risks associated with climate change and promote long-term financial stability (Grippa et al., 2019). This work emphasizes the shifting to a low-carbon economy, rather than only concentrating on risk sensitivity management, so as to improve long-term resilience. In fact, the closer we get to a world with no emissions, the less likely it is that climate risks would materialize or affect the financial system.

[1] European Commission (2019a)

2. Climate risk definition

Many regulators define two related categories in the field of climate risk: transition risk and physical risk. These categories are considered through the paper "The regulatory response to climate risks: some challenges" from BIS publication (Coelho & Restoy, 2022). It has also been considered into the European Commission's "Guidelines on non-financial reporting of climate-related information" (European Commission, 2019b).

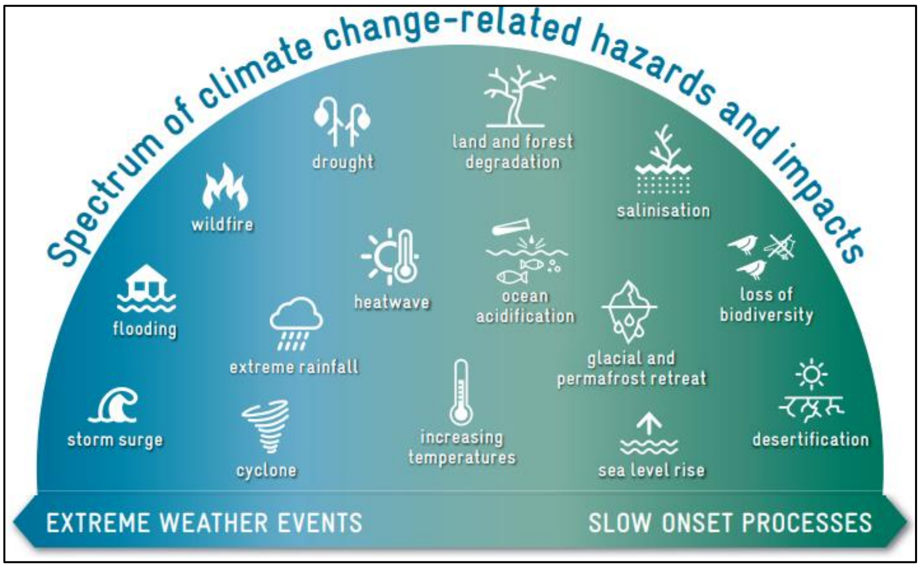
2.1. Transition risk

Many regulators define two related categories in the field of climate risk: transition risk and physical risk. Both are considered through the paper "The regulatory response to climate risks: some challenges" from BIS publication (Coelho & Restoy, 2022). It has also been discussed in the European Commission's "Guidelines on non-financial reporting of climate-related information" (European Commission, 2019b).

2.2. Physical risk

Physical risk is the risk associated by the potential financial losses caused by physical events that can damage physical assets, disrupt the supply chain and cause economic losses. It includes: acute physical risks, which are considered event-driven as extreme weather events (flood, cyclones, hurricanes) and chronic physical risk, which are considered driven by long-term shifts (sea level rise or chronic heat waves).

Figure 2: Physical risk spectrum[2]



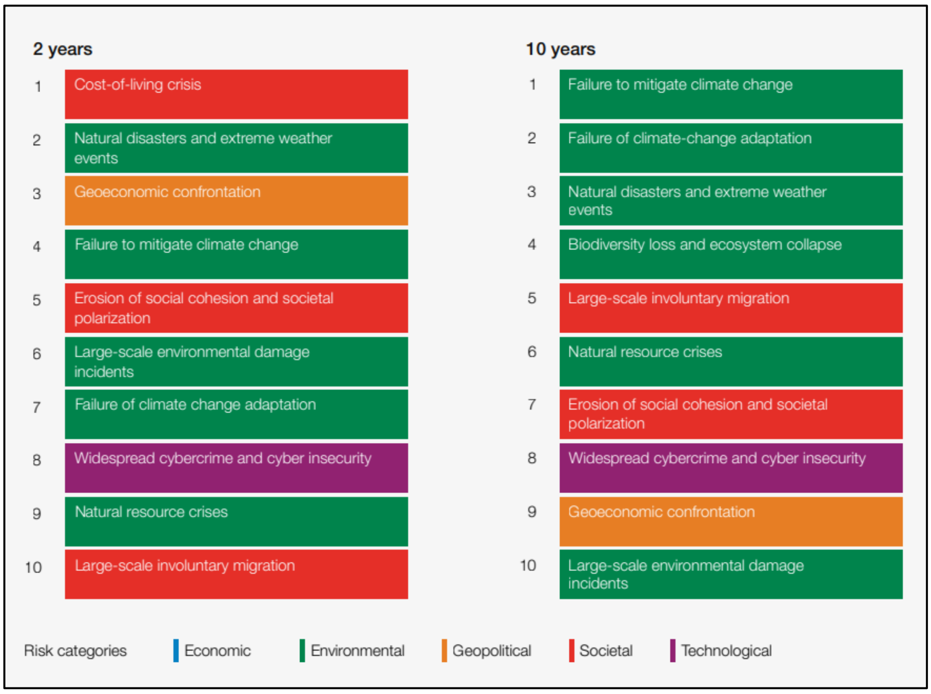
[2] Global Programme on Risk Assessment and Management for Adaptation to Climate Change (Loss and Damage) (2021)

3. Characteristics of climate risk

3.1. Significant among other risk types

The 18th edition of "The Global Risks Report" from the World Economic Forum (2023), listed the most important short-term (2 years) and long-term (10 years) global risks for 2023.

Figure 3: Top 10 Global risks ranked by severity over the short and long term[3]



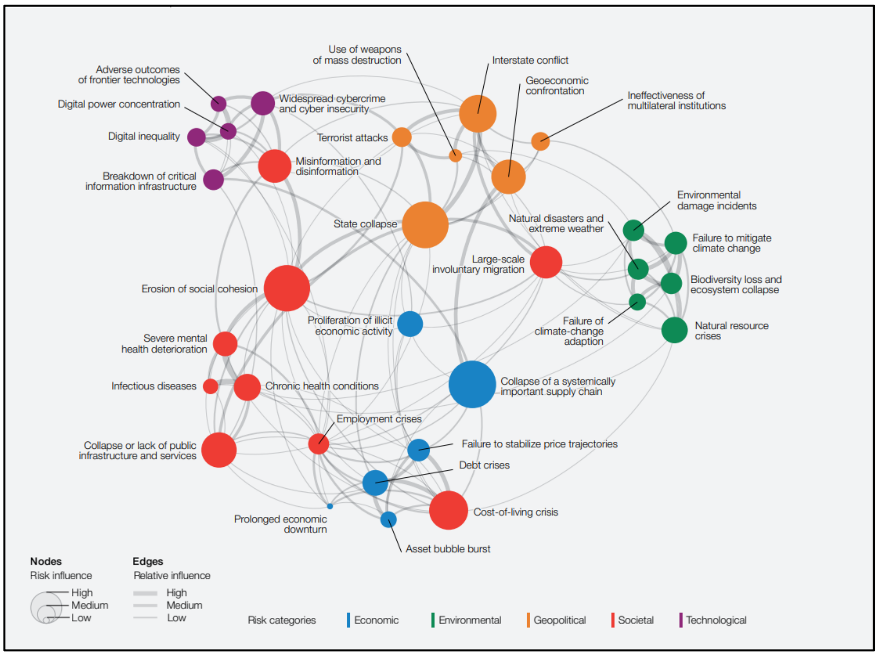
From the figure above, WEF represents that the environmental category composed 50% of the relevant risks in the short term (2 years) and 60% of the risks in the long term.

3.2. Interconnections

From the same report of World Economic Forum (2023), a map of the interconnections between different sectors has been established through the following illustration.

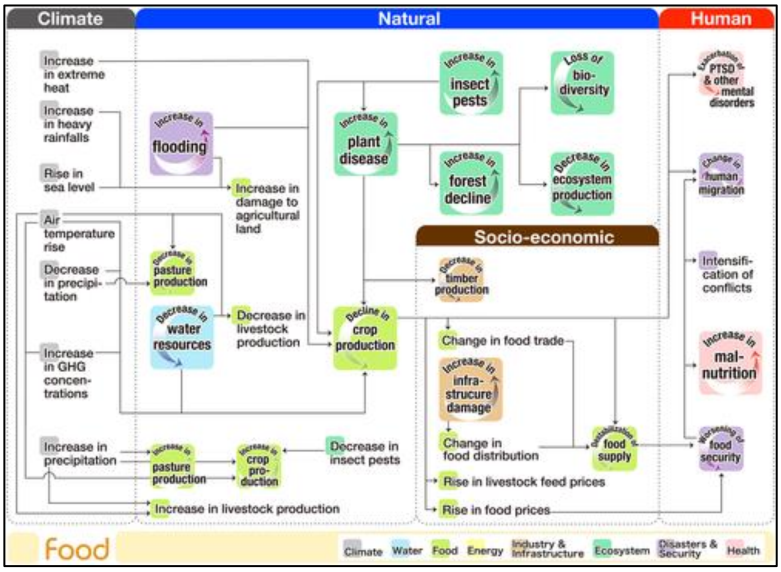
[3] World Economic Forum (2023)

Figure 4: Risk interconnections map[4]



As climate risk is linked both directly and indirectly to numerous sectors requires a properly identification, as there is not one climate risk, but many. According to a study by Yokohata et al. (2019), 91 climate risks can be identified, with 253 causal links between them. These connections can cause a cascading effect, where one extreme event can trigger one specific factor and will then amplify the impact across interconnected systems. All the causal links are illustrated in the figure below from this study.

Figure 5: Network flowchart of climate risk interconnections[5]



[4] Ibid.
[5] Yokohata et al. (2019)

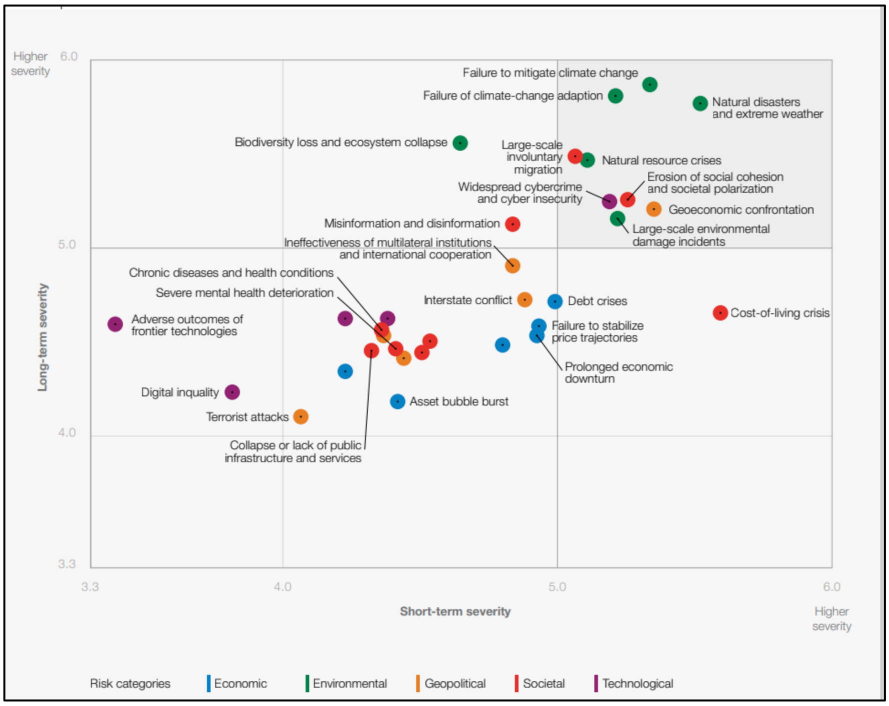
This interconnection between several sectors results in a high degree of concentration of climate risk exposure, which increases the likelihood of climate risk becoming systemic. This concentration varies according to region, sector or company (Baranović et al., 2021).

These connections are not only external but also internal, what is commonly known as a feedback loop phenomenon. The Oregon State University (2023), through an international collaboration with scientists, has identified 27 accelerators capable of creating and amplifying feedback loops. This highlights a chain of cause and effect in which the effects influence the initial action itself, forming a feedback loop.

3.3. Severity

The 18th WEF report (World Economic Forum, 2023) also includes a graph showing the severity of different sectors according to their short- and long-term impact. As seen in the figure 6, almost all of the ecological risks are represented at the top of the severity scale (4 of the 5 climate risk types), in both short- and long-term terms.

Figure 6: Relative severity of risks over a 2 and 10 year-period[6]



If we address this on a European scale, the financial losses due to climate change amount to more than 487 billion within the 27 European countries over the last 40 years (European Union, 2022). As said in the scenario created by NGFS, the "disorderly scenario", transition risk over

[6] World Economic Forum (2023)

the next 3 years could lead to a market and credit risk loss of 70 billion euros (European Central Bank, 2022a).

Conceptually similar work has also been done by Quiggin (2018) in which he supports the importance of the tail-risks of climate risk, which describes a greater likelihood of low-probability but high-impact events occurring, therefore he insists that a focus on the median value for climate risk sensitivity will give a serious underestimate of the severity of climate change.

3.4. Probability

In the case of climate risk, extreme events are more likely to occur due to the raise in global temperature (Clarke et al., 2022), and this warming is likely to increase as the years go by. Indeed, according to World Meteorological Organization (2022), there is a 50% chance of exceeding the 1.5 degree threshold over the next 5 years. It is important to bear in mind that this probability has been revised upwards over the years, from 10% between 2017 and 2021. As a result, this prediction may therefore be temporary, and may vary depending on the appearance of new studies.

Therefore, if the rise in temperature has a substantial likelihood of taking place in the foreseeable future, this boosts the probability of extreme events and the financial damages inherently associated with them.

3.5. Non-linearity and non-stationary relationships

Climate systems and their interactions with socioeconomic factors frequently exhibit nonlinear and nonstationary characteristics. This suggests that traditional linear models may not adequately capture the complex relationships and interactions between climate variables, economic factors, and physical systems, requiring the development of more sophisticated modelling approaches to have a deeper understanding of the phenomenon (Baranović et al., 2021).

In the field of the impacts of non-linear movements, special attention needs to be paid to the term “tipping point”, which describes a point onwards there is no longer control for humans to limit the impact of climate change. A number of studies have examined that these parameters could be triggered by a global temperature change before the 1.5-2 degree limit set by the Paris Agreements. Scientists suggest that the targets set should be rapidly revised in order to overcome the potential problem (OECD, 2022).

3.6. Uncertainty

A known concern with the community is that, as Rising and al. (2022) mentions, we still have deep uncertainty about what are the impacts of current identified climate risks. Moreover, it is acknowledged that not all risks factors have been fully identified. These issues stand in the way of understanding the impact of climate risk and the procedures to model it.

4. Integration into risk taxonomy

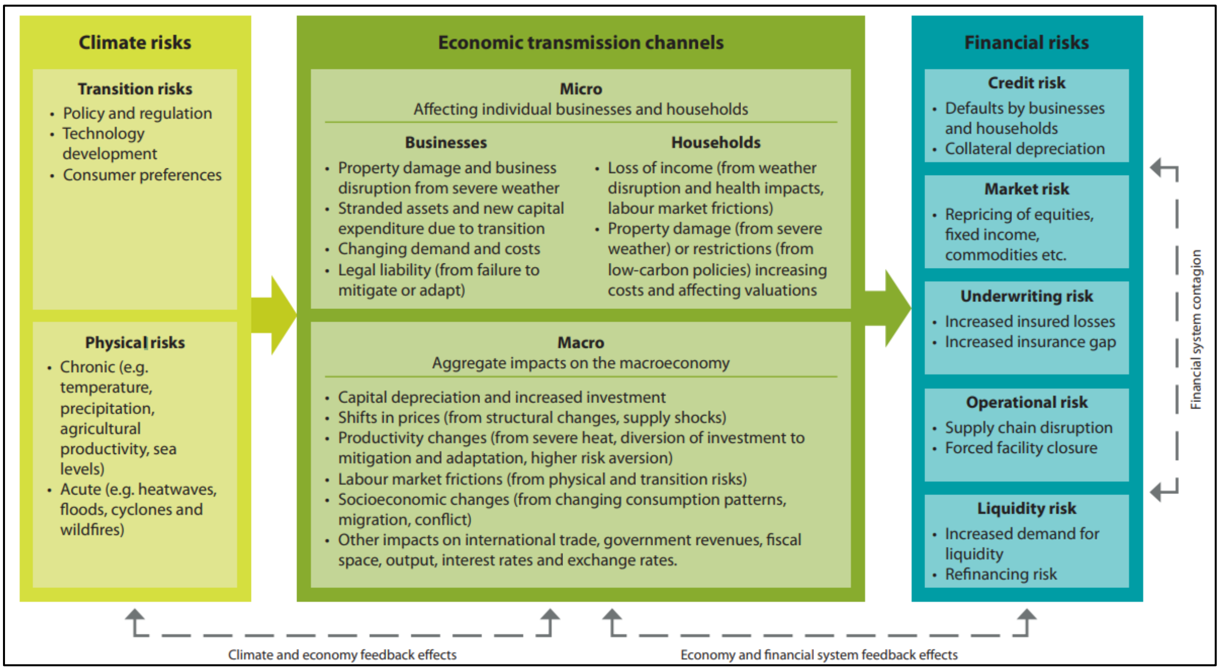
4.1. Categorisation

According to a report from Basel Committee on Banking Supervision (2021), there is no relevant literature supporting the addition of a category dedicated solely to climate risk. Indeed climate change, being a source of structural changes, has effects on the financial system by many different ways as defined in the "Guide on climate-related and environmental risks". (European Central Bank, 2020). As a result, climate risk can be considered through the current traditional risk categories. This view, underlined by the Basel Committee on Banking Supervision (2021), is supported by different supervisory authorities such as the ACPR, PRA, NGFS and the Netherlands Bank.

4.2. Link with standard category types

In order to translate the link between climate change and the traditional banking framework, Basel Committee on Banking Supervision (2021) and NGFS (2021b) have identified two important terms, the "drivers" and "transmission channels", illustrated in the figure below.

Figure 7: Climate risks to financial risks[7]



4.2.1. Drivers

Drivers are the various climate-related changes that have a potential financial impact on the economy. As defined in the previous section, climate risk drivers are related to physical risk

[7] NGFS (2022)

and transition risk. Numerous examples can be enumerated, one being the increase in chronic climate changes (rising sea levels, erosion) and acute climate changes (floods, drought, high winds, and heavy snowfall) deteriorating facilities and infrastructure, increasing the cost of maintenance for firms (Venner & Zamurs, 2012).

In terms of transition risk, through the study of "Impact of climate litigation on firm value" (Sato et al., 2023) , findings show that in average, a climate case filling with or without unfavourable court decisions reduce company value by 0,41%. Even though, the case that created the biggest reaction, saw a drop of 0.57% at the time of the filling and 1.5% after the unfavourable judgment. The authors of this study argue that firms that do not shift their high-emitting activities should expect, by a certain measure, a retraction of their investors. Further examples, by the "Task Force on Climate Related Financial Disclosures" (2017) are shown in the figure below.

Table 1: Examples of climate-related risks with their potential financial impacts[8]

Type	Climate-Related Risks[32]	Potential Financial Impacts
Transition Risks	**Policy and Legal**	
	– Increased pricing of GHG emissions – Enhanced emissions-reporting obligations – Mandates on and regulation of existing products and services – Exposure to litigation	– Increased operating costs (e.g., higher compliance costs, increased insurance premiums) – Write-offs, asset impairment, and early retirement of existing assets due to policy changes – Increased costs and/or reduced demand for products and services resulting from fines and judgments
	Technology	
	– Substitution of existing products and services with lower emissions options – Unsuccessful investment in new technologies – Costs to transition to lower emissions technology	– Write-offs and early retirement of existing assets – Reduced demand for products and services – Research and development (R&D) expenditures in new and alternative technologies – Capital investments in technology development – Costs to adopt/deploy new practices and processes
	Market	
	– Changing customer behavior – Uncertainty in market signals – Increased cost of raw materials	– Reduced demand for goods and services due to shift in consumer preferences – Increased production costs due to changing input prices (e.g., energy, water) and output requirements (e.g., waste treatment) – Abrupt and unexpected shifts in energy costs – Change in revenue mix and sources, resulting in decreased revenues – Re-pricing of assets (e.g., fossil fuel reserves, land valuations, securities valuations)
	Reputation	
	– Shifts in consumer preferences – Stigmatization of sector – Increased stakeholder concern or negative stakeholder feedback	– Reduced revenue from decreased demand for goods/services – Reduced revenue from decreased production capacity (e.g., delayed planning approvals, supply chain interruptions) – Reduced revenue from negative impacts on workforce management and planning (e.g., employee attraction and retention) – Reduction in capital availability
Physical Risks	**Acute** – Increased severity of extreme weather events such as cyclones and floods **Chronic** – Changes in precipitation patterns and extreme variability in weather patterns – Rising mean temperatures – Rising sea levels	– Reduced revenue from decreased production capacity (e.g., transport difficulties, supply chain interruptions) – Reduced revenue and higher costs from negative impacts on workforce (e.g., health, safety, absenteeism) – Write-offs and early retirement of existing assets (e.g., damage to property and assets in "high-risk" locations) – Increased operating costs (e.g., inadequate water supply for hydroelectric plants or to cool nuclear and fossil fuel plants) – Increased capital costs (e.g., damage to facilities) – Reduced revenues from lower sales/output – Increased insurance premiums and potential for reduced availability of insurance on assets in "high-risk" locations

[8] TFCD (2017)

4.2.2. Transmission channels

Transmission channels allow us to link climate risk drivers, i.e. the impact of climate change from a financial point of view, with traditional risk categories such as credit, market, operational and liquidity risk.

The NGFS (2021b) and the Basel Committee on Banking Supervision (2021) have separated these transmission channels into 2 different parts, those considered microeconomic (the impacts of climate risk drivers relevant to individual households, companies and banks) and macroeconomic (the impacts of climate risk drivers to the economy as a whole, such as employment rates, inflation, and all other macroeconomic variables).

One example of microeconomic transmission channel would be the deterioration of infrastructures, caused by the increasing frequency of extreme weather events, that would impact infrastructure, this can thus lower property value of household, affecting their income and thus increasing their credit risk. The same relation can be found for the corporations, their infrastructure will be deteriorated, affecting their value and operational reliability, increasing repair costs, therefore their credit risk, but also their operational risk by putting their supply chain functioning at risk (Maxwell et al., 2018).

One example of macroeconomic transmission channel would be that the increasing in carbon emission taxes (then being a transitional risk driver) could lower firms' profitability, and in response to this, firms could raise their prices, which could then contract individual incomes and therefore their ability to repay their debts, increasing bank credit risk (Basel Committee on Banking Supervision, 2021b). De Nederlandsche Bank (2020) give few more examples below.

Figure 8: Examples of climate risk drivers affecting traditional risk types[9]

Risk channel	Sub-type	Credit risk	Market risk	Operational risk	Other risk types
Physical	Chronic Acute	Severe weather events and long-term changing weather patterns may reduce collateral values which increases credit risk via a higher loss given default	Severe weather events may result in loss of asset values and increase volatility on e.g. commodity and/or forex markets	Severe weather events may damage the bank's branches, data centres and operations	Severe weather events leading to macro-economic shocks may increase liquidity risks
Transition	Policy Technology Market sentiment	New climate policies, technologies and market sentiment may generate stranded assets for CO_2-intensive industries which increase probability of default (via lower debt-servicing capacity) and loss given default (via lower collateral values)	New climate policies, technologies and market sentiment may generate stranded assets for CO_2-intensive industries which trigger an abrupt repricing on e.g. equity and/or bond markets	New climate policies may lead to higher liability risks of operational activities, such as outsourcing	New climate policies, technologies and market sentiment may increase reputation risks related to greenwashing[3]

[9] De Nederlandsche Bank (2020)

5. Integration into risk management cycle

After identifying the potential climate risk drivers and transmission channels affecting traditional category risks, there are different tools are available for managing and picturing these climate risks. This can be integrated into the risk management cycle (illustration below).

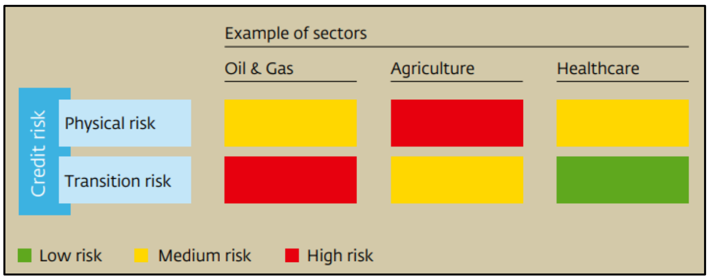
Figure 9: Risk management cycle[10]

The risk management cycle is a key element of banking operations. It generally comprises four essential stages: risk identification, assessment, mitigation and monitoring.

5.1. Identification

A convenient and frequently used tool in the field of transition and physical risk is the heat map tool. It is useful for segmenting climate risk between sectors, the traditional risk types and their severity(which in this example is characterized as low, medium and high risk by 3 different colours). Its illustration can be find in the Figure 10.

Figure 10: Identification of how climate-related risks may impact different sectors[11]

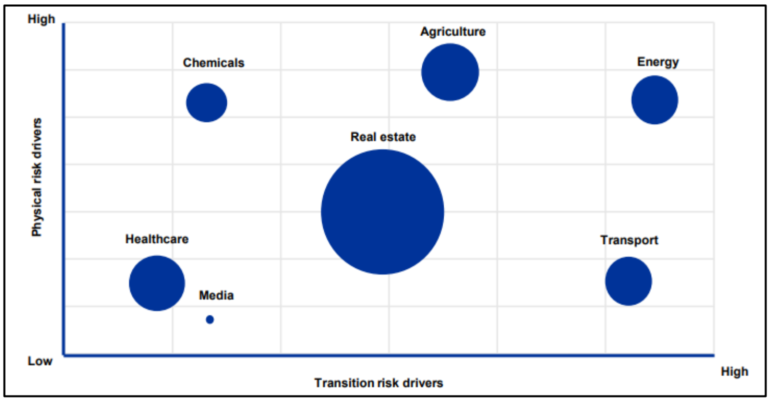


An alternative representation of the heatmap is developed in the publication "Good practices on climate-related and environmental risk management" publication of the European Central Bank (2022b), which illustrates the phenomenon with a 2 axes-graph (X-axis describes

[10] De Nederlandsche Bank (2020)
[11] Ibid.

transition risk drivers and Y-axis describes physical risk driver). In addition, the size of the bubble indicates exposure at default.

Figure 11: Identification of which risk drivers are material through 2 axes heat-map[12]



The results of the identification tools enable the bank to anticipate which follow-up actions to pursue, so as to know where to allocate time and resources in order to measure the materiality of its assets' exposure. This is done afterwards in the assessment stage.

5.2. Assessment

5.2.1. Ratings

ESG scores or climate risk scores can be used to measure the climate risk of companies or countries in which banks invest.

Banks can create these themselves taking into account, for example, their CO2 emissions per unit of energy and then comparing it with the benchmark of their industry. Then, on a qualitative level, the bank can pursue an analysis of the company's governance, strategy and risk management and include this in its rating.

In addition, banks can also draw on third-party ratings to fill any data gaps they may have. However, this can bring a number of challenges, such as the lack of standardization of these ratings between third parties, the lack of visibility on how the rating is calculated, and finally the lack of consideration of smaller companies in the ratings (Basel Committee on Banking Supervision, 2021c).

5.2.2. Scenario analysis

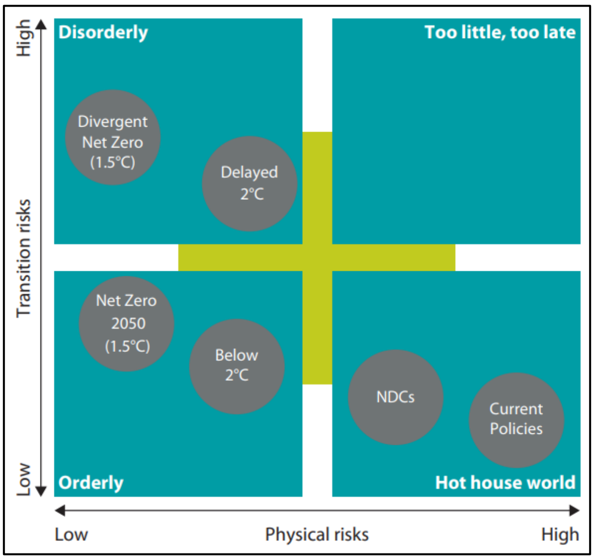
Scenario analyses are used to assess climate risk prospectively and to understand the potential impacts of different climate futures on activities, industries and investment portfolios. One of

[12] European Central Bank (2022b)

the best-known climate scenario simulations is from NGFS, which separates 6 scenarios into 3 categories, placing them on a graph which represents their implications in terms of physical and transition risk (NGFS, 2022):

- Orderly scenarios: This category of scenarios takes into account firstly the most favourable one, called the "Net Zero by 2050", where we manage to limit our emissions to 1.5 degrees thanks to strict climate rules, or secondly the "Below 2°C" scenario where climate rules are less severe and results to a 67% chance of limiting global warming to 2 degrees.
- Disorderly scenarios: the first is a scenario called "Divergent Net Zero", where we reach net zero but with policies that will drastically increase everyone's costs and therefore disrupted certain economies. The second is the "Delayed Transition" scenario, where emissions will not decrease until 2030, Only after this timeframe will stringent climate regulations be enforced
- Hot house world scenarios: A category of scenarios in which the first scenario, called "Current Policies", describes no changes applied on the currents rules to tackle climate change and predicts then a global rise in median temperatures of up to 4 degrees in 2100, and finally the "Nationally Determined Contributions (NDCs)" scenario, which takes into account the achievement of what has been pledged by countries for the time being, resulting in a 3-degree rise in global median temperatures in 2100.

Figure 12: NGFS scenario framework[13]

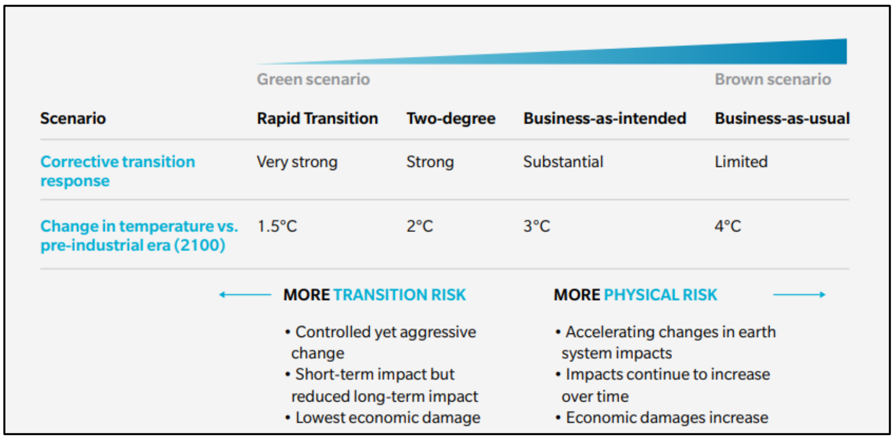


[13] NGFS (2022)

The technique of producing realistic scenarios can help banks to take into account the impact of potential transitional and physical risk on bank customers, which is also an advantage for banks themselves.

Similar contributions have been made by an Oliver Wyman paper (Colas et al., 2019), which also explores also the use of a scenario analysis. In this publication, the fluctuation between physical risk and transition risk is predicted by a future characterized by a green scenario (max 1,5 degrees of change in temperature since the preindustrial era) or by a brown scenario (max 1,5 degrees of change in temperature since the preindustrial era). An example of this can be find in the illustration below.

Figure 13: Stress test scenario of a green and a brown future[14]



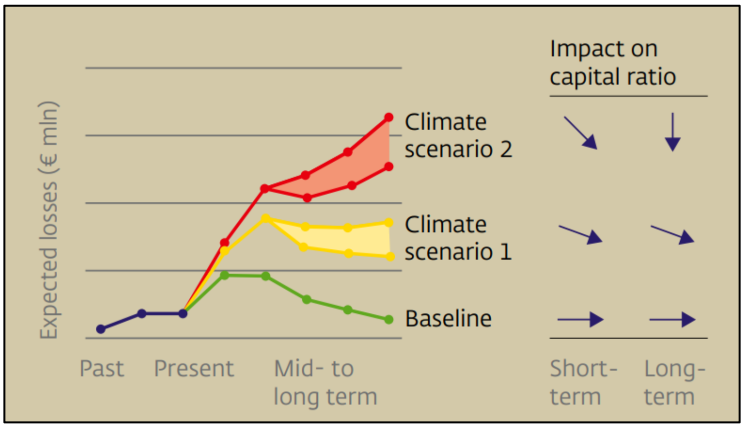
These scenarios can be used in 2 different methods: stress-testing and sensitivity analysis.

a) Stress-testing

In order to measure the bank's exposure to climate risk, a stress test scenario may be set up, in which we simulate different possible climate scenarios in order to measure its materiality. Findings of De Nederlandsche Bank highlights the consideration of potential impacts on the capital ratio on short, medium and long-term.

[14] Colas et al. (2019)

Figure 14: Climate stress test for capital ratio[15]



b) Sensitivity analysis

This analysis determines the influence of different climate scenarios on specific variables. In some cases, several parameters are modified simultaneously to observe how they interact with each other.

In the context of transition risk assessment, sensitivity analysis can be used to evaluate the potential effects of specific climate-related policies on economic outcomes. For example, researchers can use them to understand the range of economic impacts that could result from the implementation of a carbon tax. By adjusting tax-related parameters, they can observe how different tax rates influence economic outcomes (Basel Committee on Banking Supervision, 2021c).

5.2.3. Climate value-at-risk

Climate value-at-risk is an extension of the traditional Value at Risk (VaR) concept adapted to quantify the potential financial losses that could occurred due to climate-related risks. Climate VaR can be used to estimate the potential financial losses resulting from climate-related events or factors, such as physical or transition impacts on the balance sheets of financial institutions (Dietz et al., 2016).

5.2.4. Top-down and bottom-up approach

The top-down approach would allow climate-related risks to be taken into account in general measures, so that they can be passed on to investments made, such as sector performance, but

[15] De Nederlandsche Bank (2020)

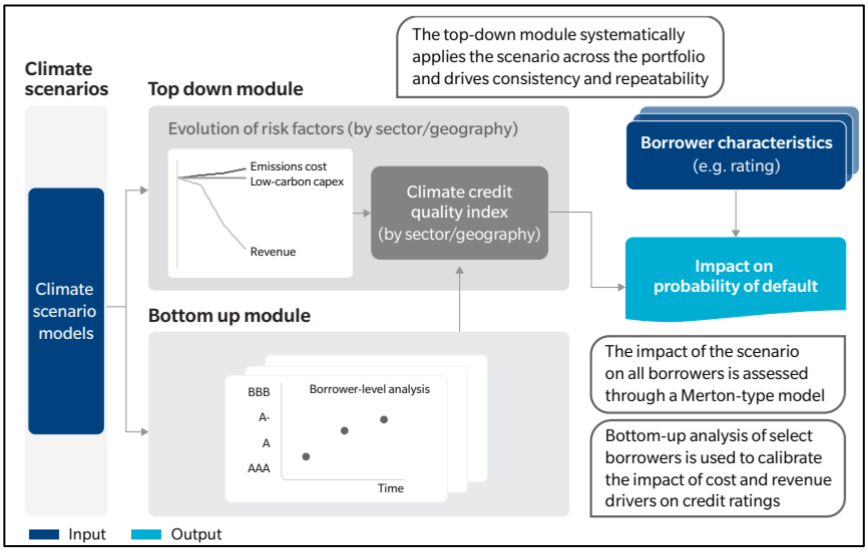
it would not include individual company risks. This could be done by means of sector ratings or an analysis of the sensitivity of general factors to climate risk.

On the other hand, the bottom-up approach assesses individual customer exposure, enabling real differentiation between customers, that may be composed of ratings or other specific factors (Basel Committee on Banking Supervision, 2021c).

A paper by Oliver Wyman (Colas et al., 2019) explores a way of using most of the above methods (stress-test, sensitivity analysis, ratings) through the use of bottom-up and top-down approaches, to include climate transition risk in the customer's PD, therefore by taking into account climate scenario models and customer characteristics (such as ratings).

The analysis is divided into 2 modules: the bottom-up module, which predicts the impact of transition risk on fuel prices, carbon, energy demand and more, in order to predict then the impact on the borrower's credit rating. While the top-down module is less borrower-specific but takes into account general risk factors (by sector and geography) and then predicts their influence on the borrower income.

Figure 15: Example of a transition risk integration methodology[16]



5.3. Mitigation

Mitigation of the bank's exposure to climate risk can be done in two ways: by reduction, where the banks take a form of engagement with the firm to make it better resilient against climate risk; or by pricing the risk of the firm properly. On the other hand, we can choose to limit it directly by various portfolio screening methods (De Nederlandsche Bank, 2020).

[16] Colas et al. (2019)

5.3.1. Reduction

a) Engagement

This relates to the idea of using investor's leverage to influence the company, so that this last integrates climate risk in its processes. This can be done by encouraging activities that can make that company better in areas of climate risk sustainability, such as choosing sustainable partners, and more. This decision to engage with the company may be an alternative to the exclusion of exposed firms from the portfolio. This could involve the bank in defining an action plan to reduce the firm's exposure to climate risk, and then establishing a follow-up to ensure that the plan is being properly implemented (PWC, 2021).

b) Pricing

One optimal solution to mitigate the impact of climate risk is that banks can adjust their pricing strategies. This can be made by adapting the price and maximum amount of their loans. For example, mortgages can face restrictions if the property does not meet energy efficiency standards. For corporate clients, this can mean higher interest rates or stricter lending conditions if they don't take enough steps to limit their carbon emissions (PWC, 2021).

5.3.2. Avoidance

a) Positive screening

This refers to the process of focusing only on companies that are climate-resilient and/or low-emitters. It can represent companies that are likely to benefit from transition to a low-carbon economy, such as renewables energy companies; or firms that are designed to mitigate the impacts of climate change properly (Deloitte Luxembourg, 2022).

b) Negative screening

On the other hand, this process excludes investments threatened by climate change. It can represent companies that are likely to be negatively impacted by the transition to a low-carbon economy as high-emitting firms, or projects that are not designed to mitigate the impacts of climate change (Deloitte Luxembourg, 2022).

5.4. Monitoring

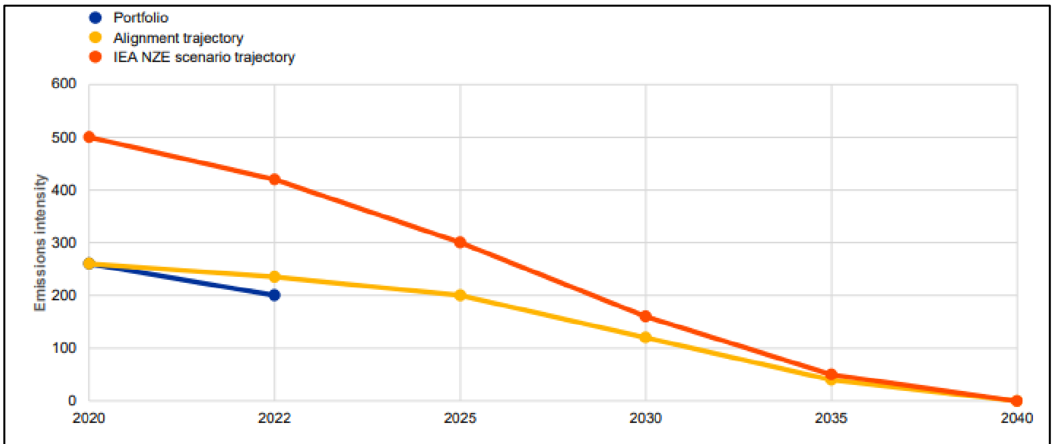
5.4.1. Indicator and risk appetite framework

Through monitoring mechanisms, banks can ensure that the processes they put in place to manage climate risk are properly managed. Firstly, banks can integrate climate risk into the use of key performance indicators (KPIs) or into their key risk indicators (KRIs).

KPIs or KRIs can be used to set targets for the future. These targets provide a clear, long-term picture of how climate risk management is progressing, so that we can better adapt to potential future regulations and ensure that we meet them on time, or simply out of ambition, expose ourselves less to this risk.

One institution, quoted by European Central Bank (2022b), has issued a KRI tracking with reference to the "Net Zero Emissions by 2050" scenario of the International Energy Agency (IEA), as referred in the Figure 16.

Figure 16: Customised example of KRI tracking[17]



Notes: IEA NZE refers to the Net Zero Emission by 2050 (NZE) scenario of the International Energy Agency (IEA) which describes a narrow but achievable pathway for the global energy sector to achieve net zero CO2 emissions by 2050, using technology roadmaps.

Depending on the type of indicator, these limits are then distributed down to the portfolio and industry levels. Both quantitative and qualitative elements can make up these limits. To effectively integrate climate-related KRIs into their risk management practices, institutions can embedded them into their risk appetite framework (De Nederlandsche Bank, 2020).

5.4.2. Governance

To incorporate climate risk comprehensively in the monitoring processes, banks may include it into its governance framework. In fact, according to an Oliver Wyman paper (Colas et al.,

[17] European Central Bank (2022b)

2019), this should be done at all levels of the company, first and foremost to provide the right guidance so that firms are in line with their risk appetite statement, including the limits and thresholds of climate risk exposure but also to monitor correctly every stage of the risk management cycle. A British International Investment (2023) publication, researched through the recommendations of the Task Force on Climate-related Financial Disclosures (TFCD, 2017), to separate the importance of governance into several points.

a) Assignment of clear roles and responsibilities

Correct governance of climate risk requires each level in the company to take responsibility. At the highest level, the assignment of a "Senior Climate Champion" for climate risk management would provide a clear framework for directing the bank's strategy towards more climate-resilient practices.

All employees need to be involved in climate risk management guidance to ensure that the bank has the necessary capacity to exert each climate risk management decisions. This means hiring enough employees (as well as the Senior Climate Champion) who are climate-related skilled sufficiently.

Finally, the frequency of monitoring must be made known to everyone and established on a regular basis. This will enable the bank to constantly improve its climate risk management practices and steer its strategy in the desired direction.

b) Cross-functional climate training

In order to ensure that each level of hierarchy and each department has enough "know-how" to ensure the application of the decisions concerning climate risk management, adapted training sessions can be carried out. Trainings should be divided according to the proximity of the employee to the customer. If the latter is on the front line, having an operative function, a training will be needed to implement risk management approaches directly with the customer, which is why, according to TFCD (2017), they need more technical and multidisciplinary training. While the 2nd line of defence, the oversight functions, should be trained to understand the impact of climate change on the bank as a whole and how to ensure resilience against it over the long term, in order to give clear and effective guidance to the 1st line of defence.

6. Regulatory capital

6.1. The rational for using regulatory capital

Risk-weighted assets like CET1 and Tier 1 capital ratios could be directly affected by the integration of climate risk into the risk taxonomy. Indeed as their calculation depending directly on the relative risks their exposed, this could have an impact on the value of the RWA of each assets.

As mentioned by a FED paper written by Holscher et al. (2022), the impact on regulatory capital depends on the nature of the loss-generating process and whether climate change creates expected or unexpected losses. If climate-related drivers increase the variance in the distribution of potential losses for a bank, it might be appropriate to consider an increase in the required capital ratio. This is because the purpose of bank capital is to absorb unexpected losses with a certain degree of confidence. In a scenario where tipping points and feedback loop effects creates a link between traditional cyclical forces and climate-related risk drivers, an increase in the required capital ratio could be considered.

Then as specified by Holscher et al. (2022), climate risks might be best addressed by forward-looking loan loss provisions and risk-based pricing at first, rather than capital. Indeed, climate change could affect the relative riskiness of specific asset types, which might require a careful assessment of the risk-weighting function. This could involve changes to fixed parameters or higher risk-weights for certain asset types. According to a European Central Bank publication (Baranović et al., 2021), macroprudential capital tools can help fortify the financial stability of banks against climate risks. This is seen as a way to balance funding and pricing distribution, highlighting that precise adjustments of this would be necessary. This integration of climate risks will have to be reflected in all the component of regulatory capital, such as in the risk weight policies and buffer requirement. This can effect strategies of investment and lending in a way that the bank will tend to focus its capital allocation towards more climate-resilient investments.

The integration of climate risk into capital requirements can follow two main rational: To improve financial resilience against climate-related financial risks, which we will call the risk-based approach and to support the transition to a net zero emissions world, which we will call the transition-based approach.

This has been a lot criticized by regulators, which uses the term "capital neutrality" to designate that the concept of capital requirements must be "neutral", i.e. pursue the sole aim of financial resilience, without promoting any financial activity or sector. Sam Woods, CEO of the Prudential Regulation Authority (PRA) support that regulatory capital is a tool to address the consequences of climate change and not the causes (Woods, 2022); While according to Berenguer et al. (2020) it may be necessary to give preference to one approach, to the detriment of the other.

We will explore the way of implementing climate risk into the current regulations put in place and the proposals that have been made in the literature to create climate resilient capital requirements.

6.2. Current capital requirement regulations

Basel's regulation, given its international financial authority, will be the regulatory framework reviewed. Various national regulatory frameworks that incorporate climate risk into regulatory capital will not be considered as "current" practice. Instead, they will be viewed as concepts that could potentially be integrated into the international regulatory framework.

6.2.1. Pillar 1

According to UK Finance (2022), banks recognize that in the future, climate risk should be included in the methods used to calculate Pillar 1 capital requirements, but for the time being, the rules established by the Basel Committee on Banking Supervision do not allow this integration. Proposals are being put forward by banks, such as a transition to methods based less on historical data and more on future projections, but this will require real joint commitment from regulators and industries. In the meantime, the banks are calling for global, standardized rules to be issued, to avoid creating competitive disadvantages, and this without premature application, so as not to increase the complexity of the current framework.

In addition, the proposal to extend the time horizon across pillar 1 regulations in order to better integrate climate risk has its limits, as this will not only have an influence from the point of view of climate risk management but, to remain meaningful, will have to include other long-term factors, such as the demographic shift.

Including methods composed of predictive scenarios instead of methods based solely on historical data may also be a way of better including climate risk, but it may also increase the unpredictability of the model, which goes against the Basel 3 bis objective of reducing model variability.

Other changes have been proposed, such as the use of external environmental metrics, such as energy performance certificates, known to correlate with financial risk outcomes in internal models or risk-sensitive adjustments. Regardless of the method chosen, financial institutions agree that the outcomes should be as uniform as possible (UK Finance, 2022).

a) Internal ratings process (IRB)

The European Banking Authority (2022), mentions that the IRB method is more risk-sensitive than the Standardised Approach and is then better able to capture any new risk that could result in credit losses. However, given that most climate risks have likely not fully materialised yet, or not in the expected frequency or with the expected impact on credit risk, there is a need to improve forward-looking modelling to capture it.

Incorporating climate change risk within banking models is a complex task. The IRB might already possess the flexibility to integrate emerging climate risks. Observable and financially consequential climate-related risks could potentially be integrated into a bank's internal model parameters, as the probability of default (PD) or the loss given default (LGD), being the main parameters of the internal ratings based approach used for calculating credit risk capital requirements (BCBS, 2001).

A ECB paper, written by Baranović et al. (2021), mentions that the estimates (PD, LGD and EAD) of IRB are not enough detailed to capture climate risks. Moreover, these models don't take into account how they interact and amplify each other, and do not account that climate risk can vary a lot between different areas, sectors, and banks.

The reliance of these models on historical data presents a significant challenge, as climate risks are not historically being captured enough to be able to represent the real impact on the financially stability, and the severity, frequency and impact area of these risks may keep evolving, thus are not well represented by past data (FSB, 2021). Specifically, the short-term nature of IRB credit risk or market risk models might limit their effectiveness in capturing the long-term risks associated with climate change.

b) Standardised approach (SA)

According to UK Finance (2022), the Standardized Approach (SA) for determining capital requirements is relatively inflexible and might not efficiently incorporate climate risk as a newly emerging risk category. That said, aspects of the SA dependent on external credit rating categories for determining risk weights, such as 'Exposures to rated institutions' could indirectly encompass climate-related risks if these risks are included in the credit evaluations of external rating agencies. This consideration may become more significant with the implementation of the 'output floor' under Basel 3.1. (or called IIIbis/IV).

Nonetheless, there is current scepticism about whether climate-related risks are sufficiently integrated within existing credit rating methodologies. Even if these methodologies were revised to account for climate risks in a better way, some jurisdictions might decide against permitting the use of external ratings under Pillar 1. Thus, it appears that the integration of climate risk into the SA approach may prove to be a challenging and indirect process.

According to Baranović et al. (2021), to improve the ability of the Standardised Approach to capture climate risk, we need to review risk weights, with the help of consistent research into the impact of climate risk.

c) Countercyclical Capital Buffer (CCyB)

While the long-lasting effects of climate change are not directly tackled by the Countercyclical Capital Buffer (CCyB), climate change could potentially transform business and financial cycles in several ways.

Assets might become 'stranded' or new sectors might inflate and form bubbles, each introducing novel financial hazards. Furthermore, as companies transition to eco-friendlier operations, they might become more exposed to economic turbulence. Plus, if we consider a low-carbon, less oil-dependent economy, business cycles might change entirely. Adjustments to the CCyB might be necessary to address these shifts (Holscher et al., 2022).

UK Finance (2022), give as a potential use of CCyB, highlighting a potential raise of the buffer during periods of carbon-intensive credit growth and lower it outside of these periods. Indeed, if there is a lot of money being lent to businesses producing consequent carbon emissions (such as oil companies or heavy manufacturing), CCyB can be use. By increasing the buffer, banks would tend to lend less to these businesses. This could slow down the growth of these carbon-intensive industries.

d) Capital conservation buffer (CCB)

Capital conversation buffers are normally designed to absorb potential shocks, including those related to climate change. A way to differentiate traditional risk and climate risk stress losses is to measure accurately how climate-related risks stacks up against current estimates of stressed losses. If climate change exacerbates the severity or duration of economic downturns, the capital conservation buffer ratio may need adjustment (Holscher et al., 2022).

e) G-SIB buffer

According to Holscher et al. (2022), the framework of GSIB has to change in order to represent the climate risks that are systemically important for the banks playing an important part in the financial stability.

6.2.2. Pillar 2

The existing Pillar 2 framework is potentially flexible enough to account for climate risks as it is already designed to be bank-specific, to cover risks which are underestimated or not covered by Pillar 1 and to account for the needs and circumstances of differing jurisdictions.

According to UK Finance (2022), the flexibility inherent in the current Pillar 2 framework may make it suitable for accounting for climate risks. Pillar 2 is customarily tailored to each bank's situation, designed to cover risks not fully captured or underestimated by Pillar 1, and takes into account the varying needs of different jurisdictions. Even though, some banks agree that Pillar 1 itself should be directly adjusted to fix any discovered gaps. In either scenario, the ability to design a robust and transparent methodology is crucial. So, although it appears that the Pillar 2 framework has potential for the integration of climate risk, it's also clear that additional refinement and development may be required.

According to European Central Bank publication (2023), the 2022 climate stress test (European Central Bank, 2022a) showed that most banks do not sufficiently incorporate climate risk into their stress-testing and model frameworks, which has impacted, for some of these banks, an increase in their Supervisory Review and Evaluation (SREP) scores, and therefore increased their Pillar 2 capital requirements. Into its Market risk SREP methodology (European Central Bank, 2023b), the ECB suggests taking external factors into account, including climate risks, through the standardized approach.

An Oliver Wyman paper (Colas et al., 2019) suggests including all climate risk exposures, impacting standard financial risk, in the internal capital adequacy assessment process (ICAAP). While a Deloitte publication (Spooner et al., 2022) recommends the use of the NGFS "short-term disorderly transition risk scenario" to measure the impacts of a tail risk transition scenario, which would remain within the usual ICAAP capital planning horizons. On the other hand, a longer-term analysis, which go beyond the ICAAP horizon (which is 3 to 5 years), would help to establish a long-term risk strategy.

From a liquidity point of view, i.e. the Internal Liquidity Adequacy Assessment Process (ILAAP), the European Central Bank (2020) suggests that banks include climate risk from both an economic and a normative point of view. This involves conducting forward-looking assessments under both normal and stressed conditions, considering severe but plausible scenarios that highlight key vulnerabilities. The assessments must determine whether these risks could have a significant impact on net cash outflows or liquidity reserves. If so, institutions should take this into account in their liquidity risk management and in the calibration of their buffers.

6.2.3. Pillar 3

One of the most recent examples of the inclusion of climate risk in Pillar 3 is the EBA's disclosure requirement, which calls for the deferral of ESG risks for certain banks from the beginning of 2023, and for the inclusion of all banks in the second half of 2024 (European Banking Authority, 2022b).

For this example of climate risk inclusion in Pillar 3, EBA has requested both quantitative and qualitative disclosures. The qualitative part will ask banks to publish their ESG risk management, specifying the integration of ESG into their management, roles and responsibilities of committees, functions and the three lines of defence, to name but a few.

The quantitative part of the disclosure is divided into 12 different templates, asking banks to publish their exposure to transitional and physical risk, and their actions to mitigate and adapt their processes.

6.3. Proposed capital tools

6.3.1. Brown penalising factor (BPF)

The brown penalising factor is a proposal to increase capital requirements for brown loans. This can be done by increasing the risk weight or by an adjustment greater than 1 to RWAs when investing in “dirty” firms (European Banking Authority, 2022a). The “dirty” or “brown” terms describe polluting assets, and therefore associated with significant levels of GHG emissions. The idea is to discourage investment in industries or sectors that contribute significantly to climate change and to encourage a switch to more sustainable or 'green' investments.

If most banks were to reduce their investments in brown assets as part of their strategy, this would have a double-edged effect. Firstly, it will encourage and accelerate investment in "clean" assets, thereby reducing physical risk over the long term. Indeed, according to Oehmke (2022), higher capital requirements make dirty loans less attractive, so banks might start lending more to clean activities, which is called a “substitution effect”. But it could also increase transition risk. Indeed, companies considered to be high-emitters will have less access to funds, which could prevent them from transitioning their activities to greener ones, but also in the long term, bring their business model to become unsustainable and obsolete (Dafermos & Nikolaidi, 2021). Indeed, Oehmke (2022) considers that this creates an "income effect", whereby dirty firms, lacking funds, will get rid of their least profitable investments, which in this case may be green investments. As a bank, therefore, this could allow to picture the assets exposed to climate risk and set aside capital accordingly, or even reducing their quantity of brown assets to lighten their capital requirements. But reorienting a portfolio towards green assets could entail short-to-medium term financial costs, given that many brown assets currently provide significant returns, it can then increase transition risks. This increase in transition risk can also be caused if the shift away from brown assets is not well managed (European Banking Authority, 2022).

6.3.2. Green supporting factor (GSF)

The purpose of the green supporting factor is to reduce the capital requirements for green assets. This can be done by lowering the risk weights for this type of asset or by using an adjustment factor lower than 1 for the RWAs (European Banking Authority, 2022a).

According to NGFS (2021), there are no tangible conclusions as to whether green investments are safer from a financial resilience point of view than brown investments. As a result, relaxing capital requirements exclusively for green assets in order to reduce the amount of equity required does not seem a proper solution. In the long term, this could lead to a "green bubble", indeed this incentive could end up to irrational investments without picturing the potential losses correctly, which would have an even greater impact on global and the bank financial stability (Aramonte & Zabai, 2021). The European Banking Authority (2022) suggests a sub-type of the GSF, which is the sectorial green supporting factor, in order to precisely identify the exposure of companies according to their sector, activities or project. These will be identified and classified thanks to the EU Taxonomy of environmentally sustainable activities. This factor would then be applied after the RWAs have been calculated using the IRB or Standardised Approach.

6.3.3. GSF and BPF merged

According to Berenguer et al. (2020), because the two last factors (GSF and BPF) are still controversial, there is some reason to explore using both at the same time. However, as previously stated, there are no concrete conclusions that investing in green assets is better for financial resilience. Capital neutrality would be hard to achieve, as it would be a constant balancing act between the 2 factors, bearing in mind that the merge of the factor is most likely to penalize brown assets. Aside from carbon neutrality, this may well encourage an acceleration in the allocation of capital to green investments.

Esposito et al. (2019) has suggested a way of using the principles of the brown penalising factor and green supporting factor by proposing the Environment-risk Weighted Asset (ERWA).

This is a proposal to modify the RWA in order to internalize the borrower's pollution risk. To do this, a "pollution factor" is multiplied directly to the RWA, which has as its benchmark the number 1, representing an activity that produces no pollution and/or has no positive environmental impact. The range of this factor is from 0.5 to 1.5, describing the degree of pollution removed/emitted by the activity, with 0.5 representing a completely green activity and 1.5 polluting accordingly. This method has certain limitations: it depends very much on the risk-weighing framework taken into account in the legal framework at the time, and could also be of great benefit to regulatory arbitrage. Country having different energy mix, dependency on commodity and its global chains can influence the weight of this ERWA. The case study (In Italy) brought by the author has shown that the tool is stable and not too much penalizing for banks, thus not harmful for the resiliency of the bank or economy as a whole.

6.3.4. Green Weighting Factor (GWF)

The green weighting factor integrates the idea of including the benefits of the green supporting factor (GSF) and brown penalizing factor (BPF).

Mentioned by Berenguer et al. (2020), this is an internal factor using a 7-level scale (each represented by a colour) created by Natixis. This represents the customer's climate score, which can give a negative (up to 24%) or positive (up to 50%) adjustment to the assets weighed according to their position on this scale. Two categories are envisaged: financing for a specific asset or project, and general-purpose credit, the first being automated. To this end, the level-scale rating is determined by a decision-tree system made up of 49 decisions, which in the end rates the customer; project or asset. This first takes into account the sector, each of which has an assigned score, and then determines the relevant scores and adjustments to be made according to this sector (industrial or geographical), before moving on to the decision tree, taking into account more deeply the characteristic of the customer/project/asset and deliver the scoring that will affect the weight of the risk.

6.3.5. Systemic Risk Buffer (SyRB)

The so-called systemic risk buffer does not exist into Basel regulatory framework but is already used by numerous countries in Europe. European Commission (2021) considers that the "systemic risk buffer" is used to address various kinds of systemic risk, which can include risks related to climate change. According to Monnin (2021), we can introduce a "climate systemic buffer" that would be integrated into the so-called systemic risk buffer. But he discredits the use of a similar systemic risk buffer for all banks, including climate risk, on the grounds that this would dilute its effectiveness in capturing real systemic climate risk. He calls for a systemic buffer specific to each bank or financial institution. The author find 2 countries that use it currently: Austria and Denmark, that have implemented a buffer so that banks keep money to protect the exposure of their assets considered to be at high climate risk.

This concept of "Climate systemic buffer" has been highlighted by UK Finance (2022). It would be similar to how the G-SIB (Global Systemically Important Banks) buffer works. Banks would be given scores based on how much they are exposed to climate risk. If the rating is high enough, meaning it is heavily exposed to climate risk, the bank would have to hold this extra buffer.

Indeed, according to Monnin (2021), many banks believe that a buffer for systemic risk should only be considered when there is a clear need to increase overall capital. Current analyses, such as climate stress tests, suggest that existing capital may already be sufficient to manage expected climate-related losses. Implementing this buffer without clear risk justification could lead to unnecessary overcapitalization of the bank. The Financial Stability Institute (FSI) has also warned that applying a macroprudential framework to systemic climate-related financial risks could be counterproductive at this stage.

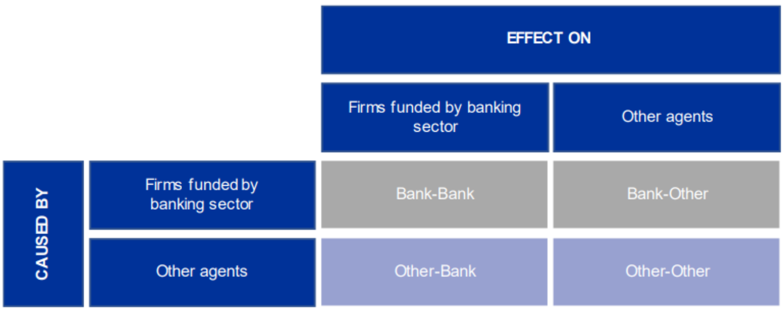
Regulatory publications have suggested that the systemic risk buffer is a potential macroprudential tool for managing systemic climate risks. It is flexible and can be applied in a number of ways, such as, a climate-specific buffer for companies based on their exposure to climate risk (as specified earlier), a system-wide systemic buffer for all banks, or a sector-specific buffer to address risks related to certain geographies or activities.

The System-wide Systemic Buffer would create an additional layer of protection that all banks have to maintain, much like the existing Countercyclical Capital Buffer (CCyB). However, instead of adjusting this buffer in response to normal ups and downs of the economy (which is what the CCyB does), this new buffer would be adjusted based on systemic climate risks. This means the buffer would increase if the overall risk from climate change to the banking system increases, and decrease if the risk lowers. The second buffer, the Sectoral Systemic Risk Buffer, would be a buffer requirement according to additional risks materialised by lending to particular geographies or activities.

Further research is needed to understand the interaction between climate and systemic risk before designing systemic risk buffer principles. Sector- or company-specific SyRB could have unintended consequences, such as penalizing assets or companies in transition, or be less effective than integrating climate risks directly into Pillars 1 and 2. Of the SyRB implementations described, the systemic approach seems the least likely to lead to negative consequences (UK Finance, 2022).

6.3.6. Double materiality consideration

Figure 17: Specific categorisation of climate risk[18]



A publication edited by European Systemic Risk Board and written by Oehmke (2022), has explored a way to include the double-materiality aspect of climate risk.

It takes into account 4 categories: The "Bank-Bank" category takes into account the activities of banks that can influence the banks themselves. The "Bank-Other" takes into account the impact of bank activity on others, i.e. outside the banking sector, such as consumers and businesses. The "Other-Bank" takes into account the impact of consumers and businesses on the banking sector. And finally, the "Other-Other" category takes into account the impact of

[18] Oehmke (2022)

consumers and businesses on themselves, thus outside the banking sector, which the author points out is not very useful in the context of financial resilience.

If we consider only financial stability, this can be represented by "Bank-Bank" and "Other-Bank", but if we want to know to what extent we are acting on the climate, which is therefore the double-materiality perspective, we can also take into account the "Bank-Other" category. For the author, it is a way to explore how could exploit capital requirements in order to favour green investments.

The research conducted by the author found that when firms engaged in carbon-intensive activities are facing moderate transition risks, it is optimal for banks to increase the capital requirements for loans funding these activities. This approach provides a larger equity cushion to absorb potential losses. Importantly, the aim is not to drive these loans out of the banking system, so this approach could even result in crowding out loans to clean firms. When transition risks intensify, the bank may further raise capital requirements for these "dirty" loans, aiming at a point to incentivise the migration of such loans and associated risks out of the banking sector. However, the primary goal of the bank is not to exclude the carbon-intensive activities but rather to protect itself from climate-related risks.

According to Oehmke (2022), using capital requirements as a mean of promoting the transition to a low-carbon economy is probably not effective enough. Firstly, because emitting activities are often more profitable than non-emitting ones, thus if we want to penalize brown assets intensively enough to favour green assets, we risk to sacrifice financial resilience. And even if this is established, brown firms will still be able to find other sources of funding. The author therefore calls for direct interventions, such as carbon taxes to have a direct impact on the profitability of high-emitting firms. Finally, he points out that capital requirements can play an indirect role. Indeed, it can ensure the introduction of carbon taxes or other types of taxation by ensuring that there is enough capital to absorb potential losses, thus avoiding an impact on financial stability.

7. Bank supervision

Bank supervision can encourage and give more resources to banks to integrate climate risk into their capital requirements and risk taxonomy. Indeed banks are facing challenges to tackle climate risk, UK Finance (2022) differentiates these challenges between "capability gaps" and "regime gaps".

7.1. Capability gaps

This reflects the lack of resources that banks have to properly understand climate risk. This is due to a lack of data or limitations in modelling techniques.

7.1.1. Data gaps

According to the Financial Stability Board (2022), filling the data availability gap is an important aspect of capturing climate risk correctly. Data limitations are one of the biggest challenges in understanding the impact of climate change, and therefore correctly measuring its impact on the bank. Despite this, the supervisors emphasized that this challenge should not be an excuse for not including climate risk in the bank's processes, and that it should find ways to circumvent this lack of data, such as appropriate proxies and estimates (Spooner et al., 2022).

Data can be broken down into 3 characteristics: data granularity, comparability and relatability.

a) Granularity

Banks need detailed data when it comes to climate risk in order to make risk assessments that make sense for their operations. The authorities should therefore start by requesting reports from the supervisory authorities to get a substantial amount of data, in order to estimate the risks more easily. If information is lacking, relevant proxies or estimates should be put in place.

b) Comparability

This data needs to be standardized in the disclosures of the impact of climate risk on banks, so that it can be compared between banks, industrial sectors and geographical areas.

c) Reliability

Apart from the potential lack of available data on the impact of climate change thanks to the disclosures made by banks, institutes and companies, we also need to ensure that these players are able to measure this data accurately.

7.1.2. Modelling gaps

Larger institutions may have more advanced capabilities to assess and report climate-related risks thanks to their greater resources such as financial/human capital, whereas smaller institutions may lack the resources to take climate risk into account, despite being potentially vulnerable to it.

7.2. Regime gaps

Regime gaps are the challenges posed by the design of the regulations themselves, due to the current use of methodologies and their limitations to capture climate risk.

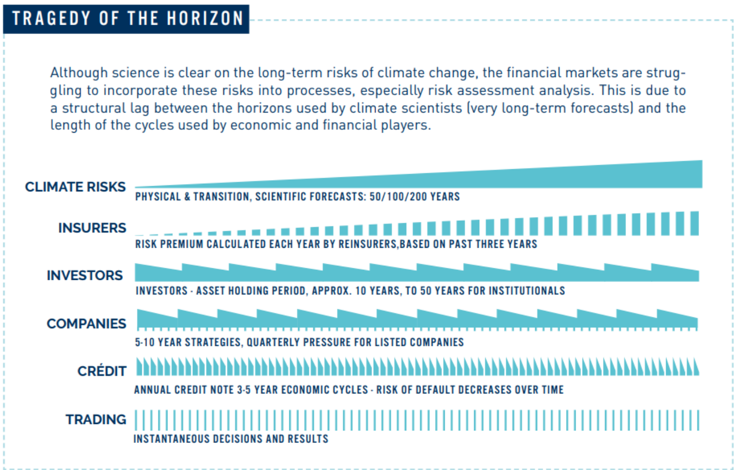
7.2.1. Forward-looking climate risk assessment

Due to the specific characteristics of climate risk, this may be not suitable to use the same methodology as the one used to measure traditional risk exposures. One of the limitation is the wide use of historical data to predict the potential exposure of assets. Indeed, historical data is not a good predictor when it comes to predicting future climate risk. This means that current models and methodologies, which do not rely solely on historical data but also incorporate predictions, will have to be favoured to take into account the long-term impacts of climate change.

7.2.2. Extended time horizon

The models recommended by the regulations are concentrated on a short timeframe (usually around one year), where climatic risks materialize over a longer period. Regulators and supervisors would therefore need to issue new risk analysis designs that involve a longer-term horizon. It is not concerning solely modelling tools, but also strategic planning and decision making processes (Basel Committee on Banking Supervision, 2022). An illustration of these differences is presentend in the figure below.

Figure 18: Time-horizon difference between sectors[19]



7.3. Potential Regulatory Enhancement Initiatives

7.3.1. Climate disclosure frameworks

To reduce the current lack of data that banks are faced with, establish legal frameworks to make companies disclose their climate-impacting activities may be a solution. A concrete example would be the new European CSRD rules, which introduce new requirements of disclosure on the impact of companies on the climate. This will be adopted by the European Commission in June 2023 and will extend over time to cover all European companies, starting with the biggest in terms of number of employees and/or sales and/or total assets to finally take all the businesses into account.

7.3.2. Global climate stress tests

Global climate stress-test may help fill data gap. According to European Central Bank (2022a), it helps to identify climate systemic risks in the financial system, helps to establish informal policy decisions and finally promotes transparency and accountability, so that it holds banks accountable for managing climate risks correctly.

7.3.3. Guidance and best practices

In order to encourage better risk management practice and share good practices, supervisory authorities can provide guidance and best practices to banks regarding the integration of climate risks into their risk management frameworks. To help smaller banks and financial institutions that lack resources, regulators should take into account the individual characteristics of each bank, such as their size, nature and risk profile in their regulatory obligations. This guidance

[19] Finance for Tomorrow (2019)

may include methodologies for assessing climate risks, establishing governance structures, and incorporating climate considerations into decision-making processes. It helps banks align their practices with industry standards and expectations. There is numerous example from authorities such as “Guide on climate-related and environmental risks” from European Central Bank (2020) or “Principles for the effective management and supervision of climate-related financial risks” from Basel Committee on Banking Supervision (2022c).

7.3.4. Incentives and taxation

This can help banks to factor climate risk better and in an easier way, and also direct investment towards low-emitting firms. Indeed, according to Grippa et al. (2019), carbon taxes could help to send price signals about the risks banks are facing, and thus promote more resilient investments.

III. EMPIRICAL RESEARCH

1. Introduction

The Basel Committee on Banking Supervision (BCBS), responsible for setting international banking standards, has acknowledged the importance of climate-related risks giving insight of climate risk impacts on traditional risk types through specific transmission channels (Basel Committee on Banking Supervision, 2021a) and disclosed guidelines of good practices (Basel Committee on Banking Supervision, 2021a). However, this suffers from limitations as it has not yet been incorporated into its requirements.

The empirical part of this paper will explore how to include climate risk in current requirements, more specifically in credit risk calculations using the Internal Ratings-Based (IRB) approach, with the equation model being the asymptotic single factor risk model (ASFR).

This could be a solution to the current data gap in climate risk. The literature focuses largely on the potential integration of climate risk into the PD factor, but as seen in the ‘Data gaps' section of the literature, banks lack the data to calculate it accurately. This is why calibrating other factors may be an alternative to integrate PD, but also a way of improving their accuracy, in order to include the specific characteristics that are solely implied by climate risk. We will then explore how these factors may be calibrated and their influence on capital for corporate assets in regular banks and large banks.

2. Methodology

To integrate climate risk into the ASFR equation model, we will take into account the specific features of climate risk that differentiate it from other traditional pre-existing risks (see the theory in the section 'Characteristics of climate risk'). The methods we will use are either regarded in literature, or developed by external sources, the source of the data collected will be specified during the analysis. The IRB credit risk capital equation, which is the Asymptotic Single Risk Factor (ASFR) equation model, is presented below:

$$K = \left[LGD * N\left(\frac{1}{\sqrt{1-R}}\right) - G(PD) + \sqrt{\frac{R}{1-R}} * G(0.999)\right] - PD * LGD * \left(\frac{1 + (M - 2.5) * b(PD)}{1 - 1.5 * b(PD)}\right)$$

The factors included in this equation are the following (Basel Committee on Banking Supervision, 2005) :

- Probability of default (PD): Probability of default gives the percentage of borrowers that might default in the course of one year.
- Loss given default (LGD) : Loss given default gives the percentage that the bank might lose in case of default of the borrower.
- Confidence level (fixed at 99.9%): The confidence level describes the probability that the bank losses exceed its tier 1 and tier 2 capital on average (99.9% would represent on average once per thousand years).
- Maturity (M): Maturity refers to the length or timeframe of time until a credit instruments is due for repayment or reaches its expiration date.

The analysis will focus on the capital requirements for corporate assets. The size of these banks influence their correlation parameters according to the Basel framework (Basel Committee on Banking Supervision, 2023). The standard correlation parameter being:

$$R = 0.12 * \left(\frac{1 - e^{-50*PD}}{1 - e^{-50}}\right) + 0.24 * \left(1 - \frac{1 - e^{-50*PD}}{1 - e^{-50}}\right)$$

This will take into account:

- The size of the bank: If the bank's total assets are worth less than 100 billion USD, this will be considered as a "regular" bank. In that case, the correlation parameter used here will be the standard correlation. If the bank's total assets are equal or higher than 100 billion USD, it will be considered as a "large" bank. This, according to Basel regulations, will affect the correlation parameter by a multiplier of 1.25.

The multiplied correlation parameter being:

$$R = 1.25 * \left(0.12 * \left(\frac{1 - e^{-50*PD}}{1 - e^{-50}}\right) + 0.24 * \left(1 - \frac{1 - e^{-50*PD}}{1 - e^{-50}}\right)\right)$$

3. Analysis

As seen before, climate risk may affect traditional risk categories, including credit risk, transmitted by a contraction of company revenues and value of their assets, being impacted by physical and transition drivers.

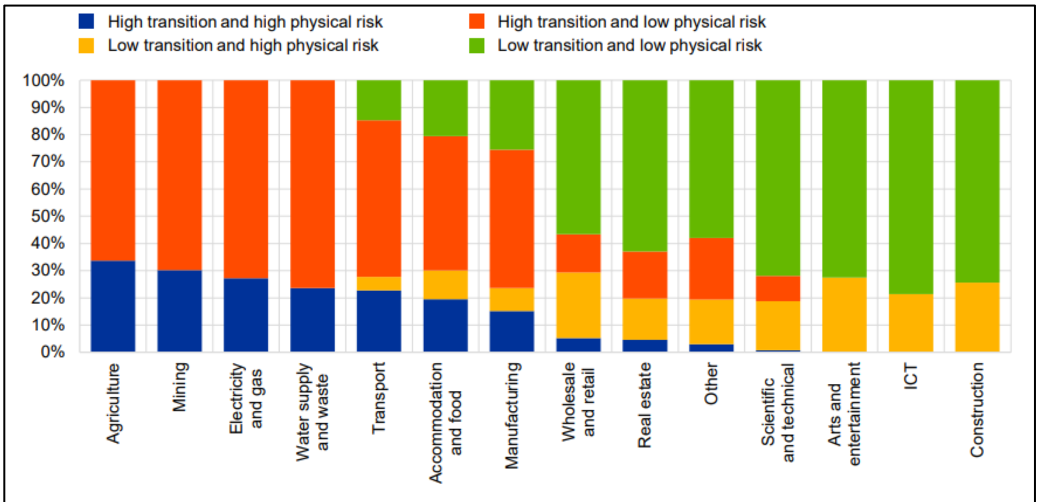
Incorporating climate risk into the Asymptotic Single Risk Factor (ASFR) model, which forms the basis of the Internal Ratings-Based (IRB) approach for credit risk, presents significant challenges, as highlighted by the ECB paper authored by Baranović et al. (2021).

We will explore in detail what can be done to the ASFR model in order to include the specificities of the impact of climate risk on its factors, with the help of external data and sensitivity analysis, in the corporate context.

3.1. Corporate context

The impact of climate risk can vary between sectors and countries. Indeed, as shown in the climate stress test of the European Central Bank (2021), this substantially vary between sectors. In fact, most 70% of agricultural businesses face high transition risk and low physical risk, with 30% of them exposed in addition to high transition risk and high physical risk, the entire construction sector faces only low transition and low physical risk exposure, and around 25% of them face high physical risk. All these results lead us to the conclusion of a certain concentration of climate risks in specific sectors.

Figure 19: Share of firms subject to climate risk by sector[20]



Source: ECB calculations based on Four Twenty Seven and Urgentem data (2018).
Notes: Firms are categorised as vulnerable to high transition risk if their relative emissions fall into the 70th percentile of Scope 1, 2 and 3 relative emissions for the entire sample. Firms are vulnerable to high physical risk if their probability of suffering from a wildfire or a river or coastal flood in a given year is over 1%. Level 1 NACE sectors are shown.

[20] European Central Bank (2021)

3.2. PD

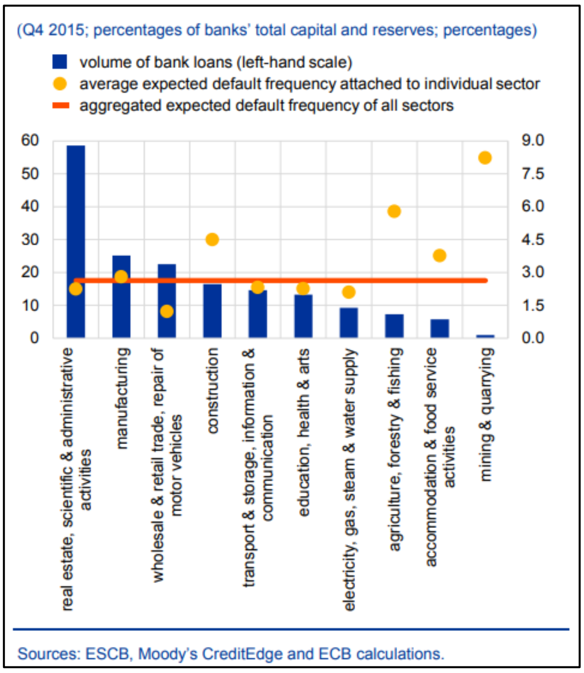
The European Central Bank (2021) climate wide stress-test has shown that in Europe, if climate risks are not mitigated, companies will face increased costs that will translate into a higher probability of default, although this may vary according to scenarios, sector and region. We will explore the influence this may have on capital requirements.

3.2.1. Methodology

We will focus our analysis on the differences between sectors and scenarios, to see which types of assets will be most affected in terms of absolute and relative differences in capital requirements. This will not only allow us to see which asset types will need the most capital requirements compared to others, but will also allow us to use today's default probability baseline to see which asset types will experience the greatest variation in their capital requirements if banks choose to include climate risk into the PD of their portfolio.

Our standard default probabilities, i.e. probabilities where the influence of climate is not taken into account, will be obtained from the European Central Bank (2016) publication on default probabilities of European companies by sector of activity. These sectors have been taken from the NACE classification system.

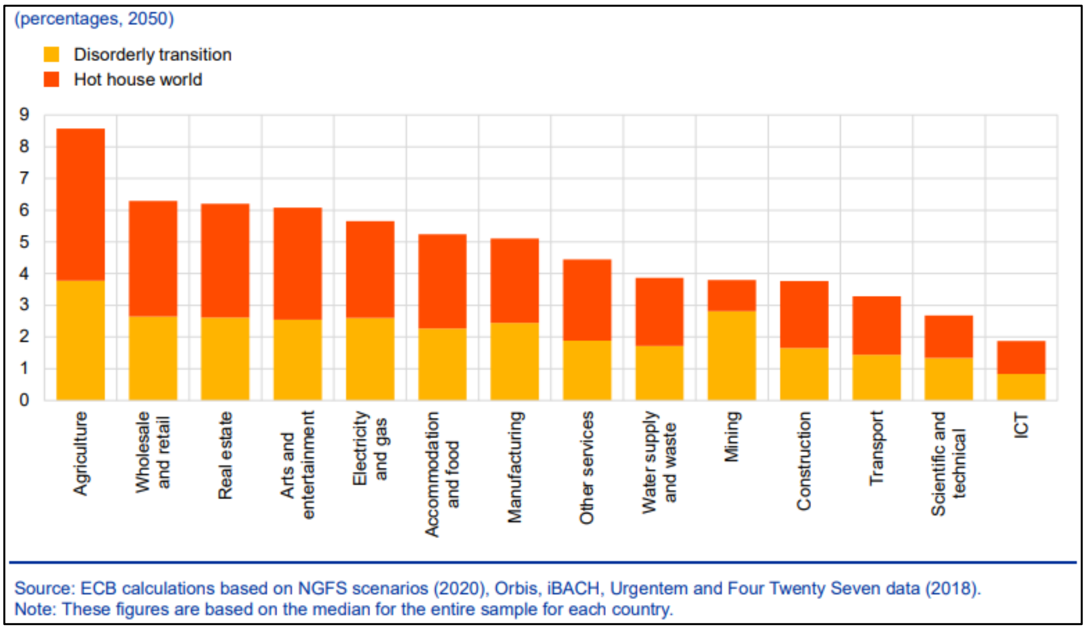
Figure 20: Probability of default by sector[21]



[21] European Central Bank (2016)

Finally, our climate-stressed default probability values are taken from the European Central Bank (2021)'s economy-wide climate stress test. In this publication, the ECB has calculated the potential changes in default probabilities by sector according to the “Disorderly Transition (DT)” and “Hot House (HH)” world scenarios. These scenarios are defined by NGFS, where the first describes a category of scenario where the transition to a carbon-free world will increase costs and disrupt the economy, whereas the second category describes a scenario where the transition will not be sufficient and will lead to a 3 to 4 degree rise in global median temperatures in 2100.

Figure 21: Probabilities of default relative to the orderly transition scenario by sector[22]



The data represents the relative changes based on the probability of default in an orderly transition scenario, this last being considered as the standard probability of default obtained from figure 20.

Following, Figure 20 represents the standard probability of default for 10 sectors, whereas Figure 21 represents the relative PD changes for 14 sectors, therefore a similar standard PD may be used for multiple different sectorial capital requirement computations. From these 14 sectors, one of them will be omitted completely (the sector "Other services") in our analysis. Refer to the table in the appendix (Appendix 2) to see which standard default probability the analysis is based on to compute the relative changes it may cause to capital requirements by sector.

[22] European Central Bank (2021)

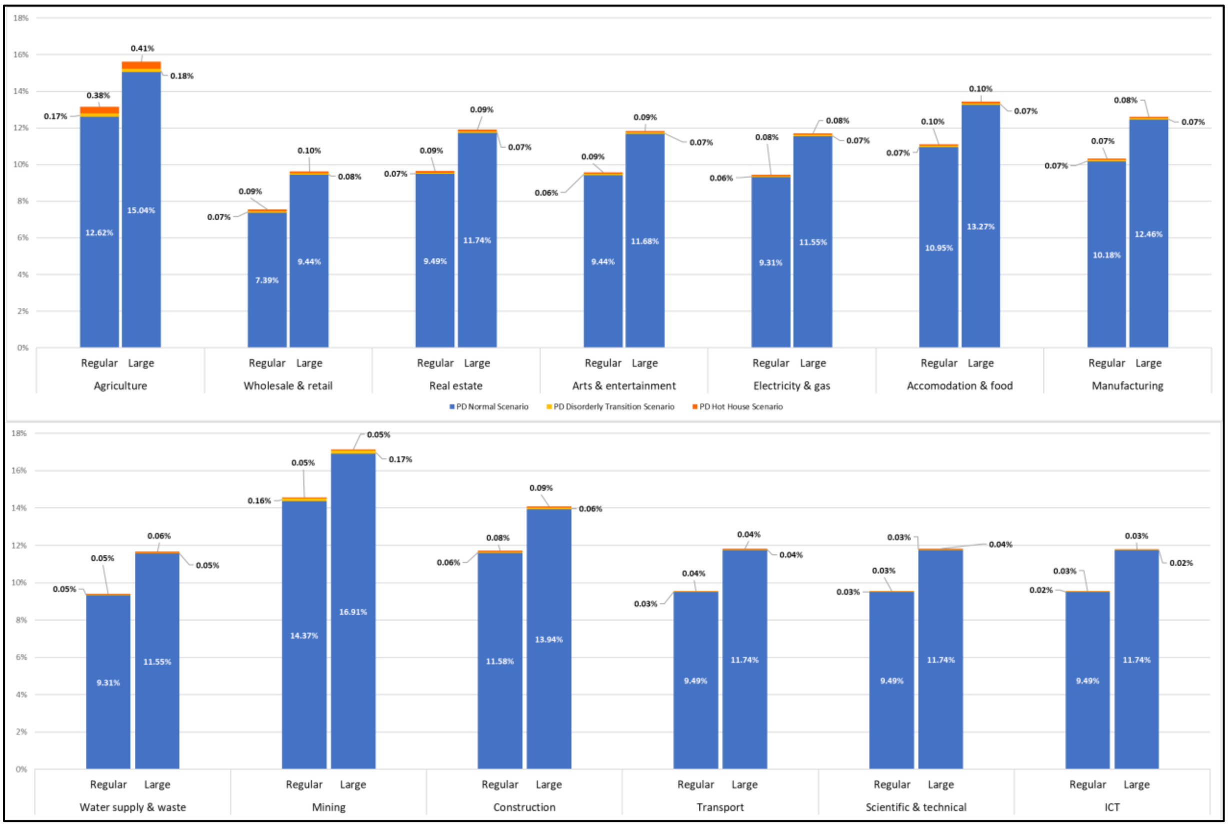
The climate-stressed PDs and LGDs under the DT scenario and the HH scenario, using the data in Figure 20 and Figure 21, can be found in Appendix 1.

To compute the impact it will have on banks' capital requirements, we will use the ASFR model, as indicated in the methodology. According to Basel, LGD values for corporates have historically ranged between 40% and 60%. We will therefore set this parameter at 45%. Consequently, Basel considers that the standard maturity is 2.5 years and will therefore be set as follows in our model. Basel then considers that the confidence interval should be 99.9% and that the minimum and maximum correlation of corporate assets should be 12% and 24% respectively (Basel Committee on Banking Supervision, 2023).

3.2.2. Results

According to the ASFR model, this will have an impact on banks' capital requirements depending on the sector of assets they hold. These variations in capital requirements are shown in the next graph, which indicates the absolute differences in capital requirements between each scenario, bank and asset type.

Figure 22: Capital requirements by sector, bank and scenario type (PD modified)



The appendix contains all the value of capital requirements, with absolute and relative differences in capital requirements by sector and scenarios (Appendix 3, 4 and 5 respectively).

- Capital absolute value

In terms of direct value of capital requirements, taking the "Disorderly Transition" scenario into account for large banks, the highest capital requirements are found in the "Mining" and "Agriculture" asset types (17.08% and 16.52% respectively) and the lowest are the "Wholesale & retail" and "Water supply & waste" assets types (9.52% and 11.60%).

If we consider the "Hot House" scenario for large banks, similar results are also observed, where the "Mining" and "Agriculture" asset types are still the highest capital requirements, bringing them to 17.13% and 15.63% respectively, whereas the lowest remains "Wholesale & retail" and "Water supply & waste", with 9.62% and 11.66% for large banks. Finally, across all asset types, large banks always experience a greater capital requirements than regular banks.

Based on the results we make the following observations:

With or without a context with climate stress, we can see that those with the highest capital requirements are those that have a higher standard probability of default (5.8% and 8.25% standard probability of default for the asset types "Agriculture" and "Mining" respectively). We can find similar relations for the lowest asset types. These results illustrate that, in terms of absolute values, climate risk incorporation into PD system will not disrupt the classification of the capital requirements for asset types. The ones considered being more demanding of security capital stay at the top of the list, even after the incorporation of climate risk for all asset types.

Large banks have greater capital requirements by the fact that the correlation parameter for large banks is multiplied by a factor of 1.25 in the ASFR model, where regular banks keep the standard correlation parameter.

- Absolute changes

The results are interesting and help to justify the differences of capital requirement.

Considering the "Disorderly Transition" scenario for large banks, the highest absolute changes are found in the "Agriculture" and "Mining" asset types (0.18% and 0.17% respectively) and the lowest absolute changes remains in the "ICT", "Scientific & technical" and "Transport" asset types (0.02 %, 0.03% and 0.04% for large banks). Taking the "Hot House" scenario for large banks, the highest changes in capital requirements are in the "Agriculture", "Mining" asset types, bringing a difference in the capital requirements of 0.59% and 0.22% respectively and the lowest absolute changes remains in the "ICT", 'Scientific & technical" and "Transport" asset types (0.05%, 0.07% and 0.07%).

These findings reinforce the general idea that large banks have higher differences in capital requirements than regular banks.

By carefully examining the data, it is found that in Figure 21, the “Wholesale & retail” sector is the second type of assets the most sensible to climate change in terms of probability of default change. Nonetheless, in matter of capital requirements this type of asset has been increased to a lesser extent than mining (being the 9th more impacted between 13 sectors). Indeed, even though the “Wholesale & retail” sector is more exposed to the climate than the mining sector, it will be required less capital changes than the latter being less at risk without climate stress, showing that the value of the overall PD is important and imply a variation in capital requirements at an increase pace the more this is high.

From the short review above, it is found that the two highest change in capital requirement, being the agriculture and mining sector, are differentiated by the impact between the different scenarios. In fact the capital requirements of the agricultural sector is much greater in a "Hot House" scenario than in a "Disorder Transition" one. While the mining sector has almost the same capital change as the agricultural sector in a DT scenario (0.18% vs 0.17% for agriculture and mining respectively), the mining sector has two time less variation in capital requirements in a HH scenario (0.59% vs 0.22%). This shows that the agricultural sector is much more exposed to the physical risk engendered by a lack of legislation to pursue the transition, than the mining sector, which is more impacted by the achievement of an efficient but disorderly transition. In general terms, the agricultural sector is therefore more exposed to physical risk, whereas the mining sector is more exposed to transition risk. The results are interesting and help to see if capital requirements are correctly adapted with what we can observe in the literature.

This is in line with Olivier Wyman's climate scenario, in which he draws up a "green" scenario that would increase transition risk and a "brown" scenario that would increase physical risk (see Figure 13).

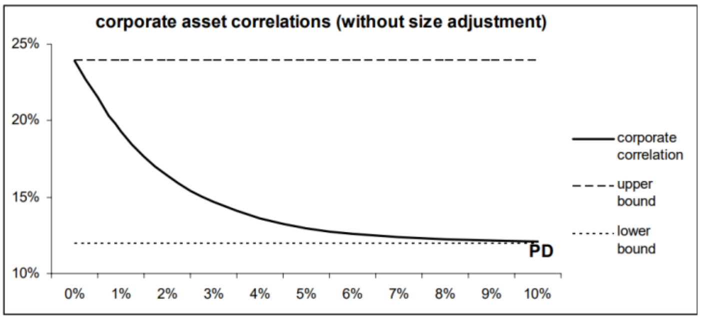
Once again, large banks are characterised by higher values for the absolute difference in capital requirements than regular banks, which can be explained by the consideration of a higher correlation of assets for these.

- Relative changes

What differs from the other findings is the difference in variation between broad and regular banks. Regarding this variation, regular banks are more affected in terms of increases in capital requirements than large banks. Indeed, after taking into account the "Hot House" scenario for large banks, the highest relative differences are found in the "Agriculture", "Wholesale & retail" and "Real estate" asset types (3.93%, 1.95% and 1.42 % respectively). For regular banks, these variations are even greater (4.38%, 2.19% and 1.67% respectively).

This, in principle, may be mainly caused by the importance that the ASFR model gives to PD when correlation varies. Indeed, the reasoning provided by Basel is that if the PD increases, the individual risk factors associated with that specific borrower (sector in this case) become more relevant to determine the loan's performance. Therefore the circumstances of this increase in probability of default is supposedly less influenced by boarder economic conditions but more by the particularity of the borrower (sector in this case). It means that the more the PD increases, the less correlation the assets is assigned. The second assumption is that the asset correlation increases with the size of the bank, being from a prudential point of view, more a systemic risk than a standard one.

Figure 23: Asset correlation function[23]



However, because the large banks' R value is already inflated (due to the 1.25 multiplication), this decrease will proportionally be less for large banks than for regular banks. In other words, for large banks, the relative change in the correlation factor (R) and subsequently in the capital requirements will be less when PD increases. This means that an increase in the probability of default (in this case for reasons of including climate risk) will disadvantage regular banks compared to large banks, since they have a lower standard capital requirements. Therefore they will face a greater shock in them than large banks.

[23] Basel Committee on Banking Supervision (2005)

3.2.3. Level playing field

a) Particularities

- Simplicity

It is expected that adding a climate risk component to the PD might involve complex climate modeling and could increase the existing complexity of the PD calculation.

- Risk sensitivity

The PD is a key parameter for credit risk, and adjusting it for climate risk could significantly improve the risk sensitivity of capital requirements. But as our results have shown, including climate risk directly in the PD computation make capital requirements less sensitive for sectors with a lower standard probability of default and put less weight on systematically more important banks.

- Comparability

Banks might use different approaches to model climate risks into the probability of default of their assets, which could impact the comparability of PDs across banks.

Table 2: Summary review of the level playing field of PD integration

Simplicity	Medium
Risk sensitivity	High
Comparability	Medium

b) Context of use and limits

Probability of default adjustments can be particularly useful when assessing sectors with high exposure to climate risk. But if data on the probability of default exposure to climate risk is limited, it may not be possible to adjust the ASFR model to incorporate climate risk.

The impact of the probability of default (PD) alone on capital requirements doesn't appear to be substantial, contrary to what might be expected from existing literature. This suggests that integrating climate risk into the PD should be conducted alongside calibrations of other relevant parameters. In addition, when considering the incorporation of climate risk into the PD, a method tailored specifically for climate risk prediction may be more appropriate rather than integrating PD into the ASFR model.

One way to avoid that the climate-stressed PD becomes ‘muddled’ would be to segregate this PD from the standard PD by using the ASFR model through a buffer (as mentioned in the literature). Thanks to a climate buffer, it might be easier to track, manage, and mitigate climate risk separately without interfering with the usual risk assessment practices. The risk sensitivity of this buffer could be adapted specifically to climate risk.

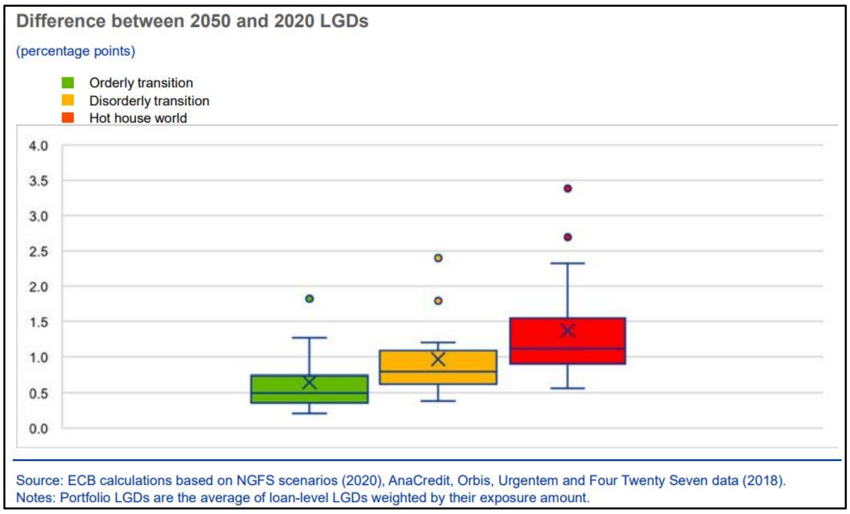
3.3. LGD

According to the European Central Bank (2021), LGDs are impacted by climate risk. This impact on credit risk LGDs is mainly due to exposure of physical collateral.

3.3.1. Methodology

Our dataset will be based on the boxplot issued by the European Central Bank (2021) which describes the average increase in LGDs across the 3 scenarios: Orderly Transition (OT), Disorderly Transition (DT) and Hot House world (HH). To remain consistent with the analysis of the integration of climate risk in the PD, we only keep the DT and HH scenario.

Figure 24: Difference between 2020 and 2050 LGDs due to physical and transition shocks[24]



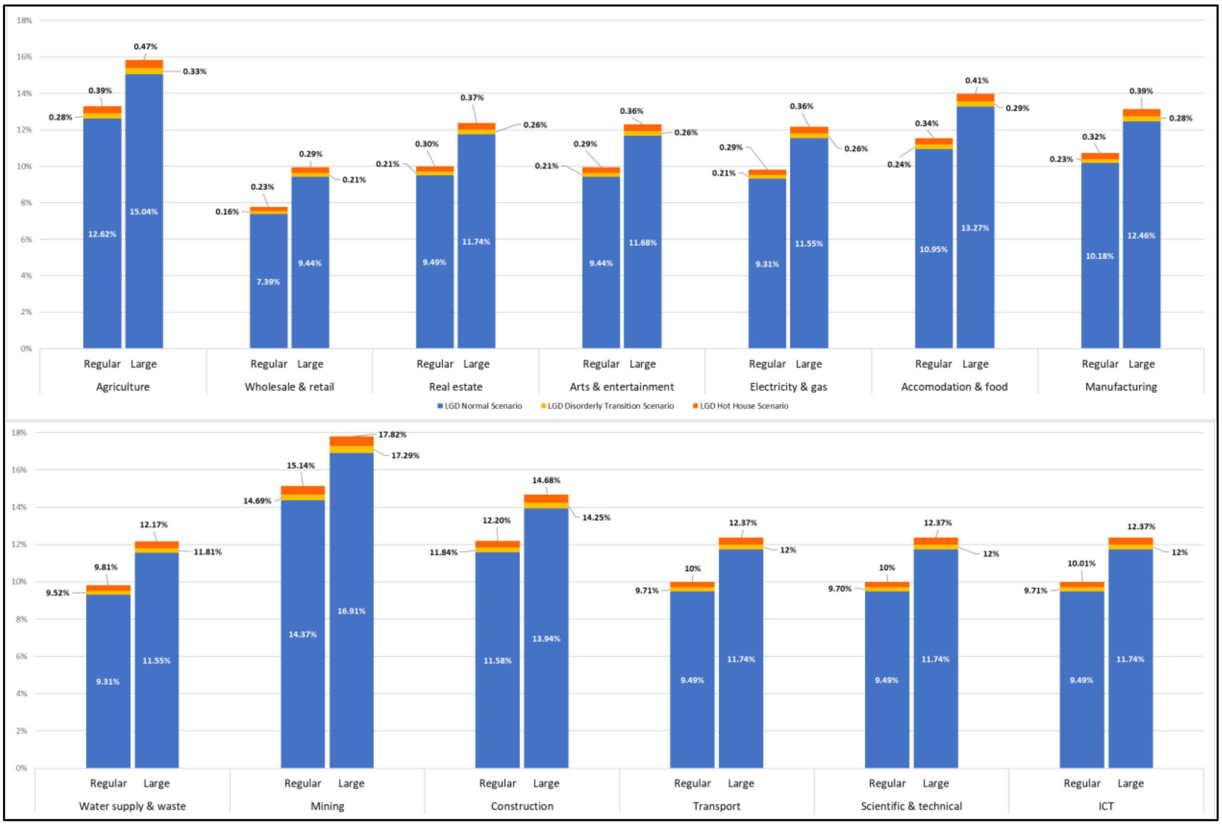
To compute the impact this will have on banks' capital requirements, we will use the ASFR model, as indicated in the PD methodology. According to Basel, LGD values for corporates have historically varied between 40% and 60%. We will therefore set this parameter at 45% as a benchmark, after which we will take into account data from the European Central Bank's box plot and observe the variation. As before, the standard maturity will be set at 2.5 years and the confidence interval will be set at 99.9%. Finally the minimum and maximum correlations of corporate assets should be 12% and 24% respectively.

As a second exploration, we will use the PD climate stressed and LGD climate stressed together with the maturity, confidence interval, minimum and maximum correlation fixed as before.

[24] European Central Bank (2021)

3.3.2. Results

Figure 25: Capital requirements by sector, bank and scenario type (LGD modified)



The appendix contains all the value of capital requirements, where the LGD has been modified (Appendix 6).

We can see that every sector has an absolute increase between 0.16% et 0.80% in capital requirements taking into account both scenario and size banks. Results show that the relative increase for every sector is 2.22% for DT scenario and 5.33% for HH scenario.

The calibration of the LGD imply an increase of the capital requirements of 0.43% in average, while the calibration of the PD did an increase of 0.12%

3.3.3. Level playing field

a) Particularities

- Simplicity

The incorporation of climate risk into LGDs can be complex. Indeed, modelling recovery rates can prove to be difficult due to the uncertainty and long-term nature of climate risks.

- Risk sensitivity

An adjustment of the LGD to incorporate climate risk can enhance the risk sensitivity of capital requirements.

- Comparability

As with PD, the integration of climate risk into LGD could lead to comparability issues if the existing banks use different methodologies or data sources to assess and incorporate climate risks.

Table 3: Summary review of the level playing field of LGD integration

Simplicity	Medium
Risk sensitivity	High
Comparability	Medium

b) Context of use

The integration of climate risk into LGD can be particularly relevant for portfolios with significant secured lending, where the collateral's value might be impacted by climate risks. For example, mortgages secured by real estate in flood-prone areas could see higher LGDs due to the increased potential for property damage.

For portfolios consisting largely of unsecured lending, the integration of climate risk into LGD might have less impact, since there is no physical collateral that could be directly affected by climate risks. In addition, if reliable data on the potential impact of climate risks on recovery rates is lacking, adjusting the LGD could be challenging.

3.4. Expected loss (PD x LGD)

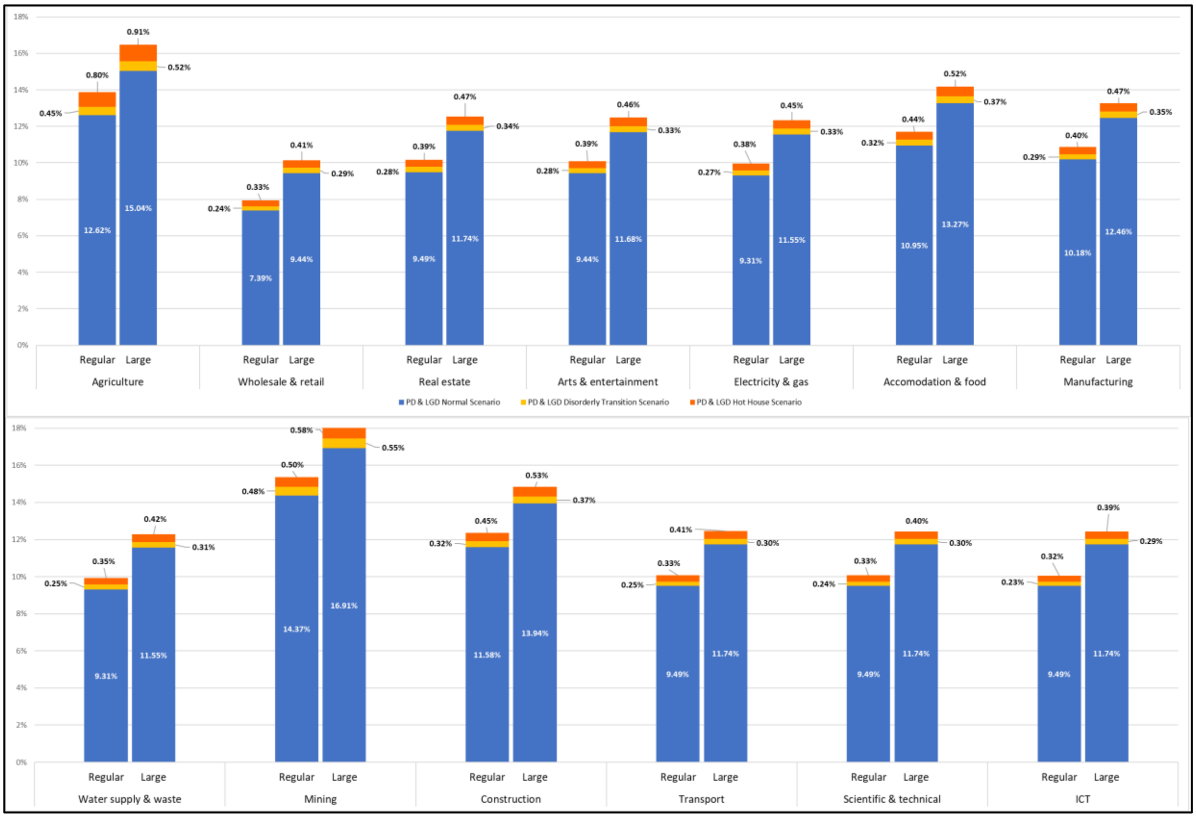
We will then examine the impact of integrating climate risk into the PD and LGD simultaneously.

3.4.1. Methodology

The methodology will mirror the Loss Given Default (LGD) integration methodology. However, in this case, the Probability of Default (PD) will not be based on standard PD but will take into account the context of the "Disorderly Transition" scenario and the "Hot House" scenario. All other factors will align with the values cited in the LGD integration methodology.

3.4.2. Results

Figure 26: Capital requirements by sector, bank and scenario type (LGD and PD modified)



The appendix contains all the value of capital requirements, where the LGD and PD have been modified together (Appendix 7).

In term of relative difference between capital requirements with climate PD and capital requirements with climate PD and LGD together is for all sectors and banks 2.22% for DT scenario and 5.33% for HH scenario, highlighting that the increase in LGD increase in a linear way the capital requirements.

If we consider the average change in capital requirements, the incorporation of climate risk through the LGDs and PDs together increased the capital requirements by 0.56%, where the LGD alone increase them by 0.43% in average and the calibration of the PD only did an increase of 0.12%.

3.4.3. Level playing field

a) Particularities

- Simplicity

The product of PD and LGD, which estimates the expected loss from a default, can become even more complex to compute when both PD and LGD are adjusted for climate risk. The complexity arises from the need to estimate the interdependencies and possible interaction effects between the PD and LGD under different climate scenarios.

- Risk sensitivity

Adjusting both LGD and PD for climate risk can capture the compound effect of climate risks on both the likelihood and extent of losses, potentially enhancing the risk sensitivity of capital requirements.

- Comparability

The increased complexity and the need to estimate interaction effects between LGD and PD could affect the comparability of capital requirements across banks.

Table 4: Summary review of the level playing field of LGD and PD integration

Simplicity	Low
Risk sensitivity	High
Comparability	Low

b) Context of use

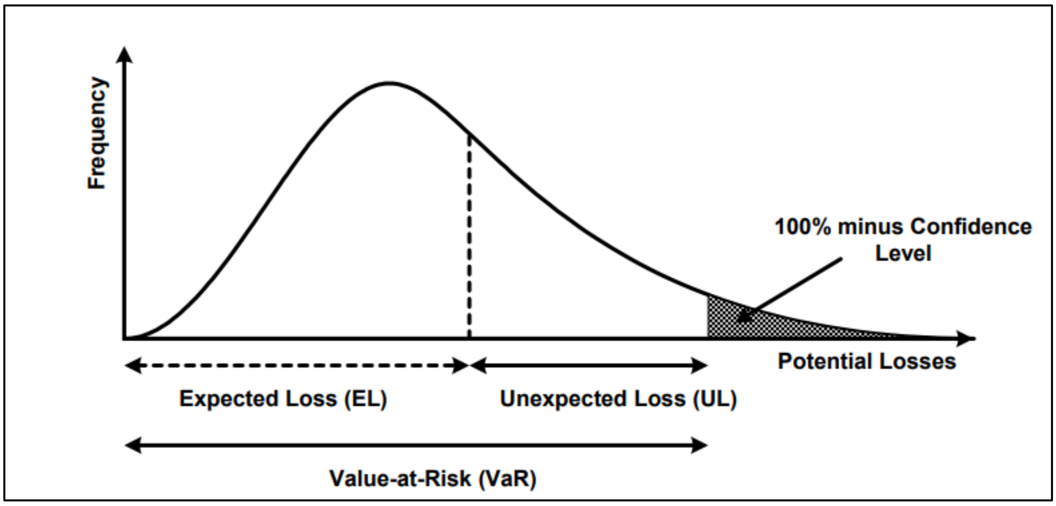
Adjusting both LGD and PD for climate risk can be useful for a holistic view of credit risk under various climate scenarios. It can capture the interaction effect of climate risks on both the likelihood and extent of losses. This approach can be particularly useful for banks with diverse portfolios spanning multiple sectors and geographies.

It should be use with highly accurate data, the complexity of modelling being more complex with the two factors together, to be sure to minimise the computation errors. Additionally if the borrower's LGD is not exposed to climate risk, this approach may be obsolete.

3.5. Confidence interval

The model ASFR makes use of the confidence interval to compute capital requirements. In this kind of model, most outcomes are expected to be relatively close to the average, with the probability of extreme outcomes ("tail risk") decreasing as you move further from the mean. Basel has set a high confidence level of 99.9%, assuming that losses exceeding the institution's tier 1 and tier 2 capital could occur more rarely, only once in a thousand years on average.

Figure 27: Bell curve distribution[25]



As mentioned earlier in this paper, Holscher et al. (2022) described that the impact of climate risk on regulatory capital depends on the nature of the loss-generating process and whether climate change creates expected or unexpected losses. If climate risk increase the variance of the distribution, an increase in capital requirements could be appropriate.

In order to integrate climate risk into the ASFR model, we can calibrate the confidence interval so that it better respects the particularities of climate risk. Indeed, what differentiates climate risk from other risks is the greater chance of extreme events that would fall into the "tails" of a normal distribution (Baranović et al., 2021), which will modify the distribution (this can be called a fat-tailed or heavy-tailed distribution). This means that there is more uncertainty about climate risk outcomes, which could mean that outcomes implied by climate could fall outside a traditionally calculated confidence interval.

In this example, one way to better take into account the tail risk characteristics of climate risk would be to increase the confidence interval, given that greater losses are expected in the future due to climate change.

[25] Basel Committee on Banking Supervision (2005)

This higher level of confidence would help mitigate the risk of underestimating capital requirements and ensures that banks maintain sufficient reserves to absorb potential losses. It recognises the limitations and potential inaccuracies of the estimation process and provides an additional level of protection against unexpected adverse events.

3.5.1. Methodology

A sensitivity analysis will be carry out to observe the impact of a calibration of the confidence interval on capital requirements.

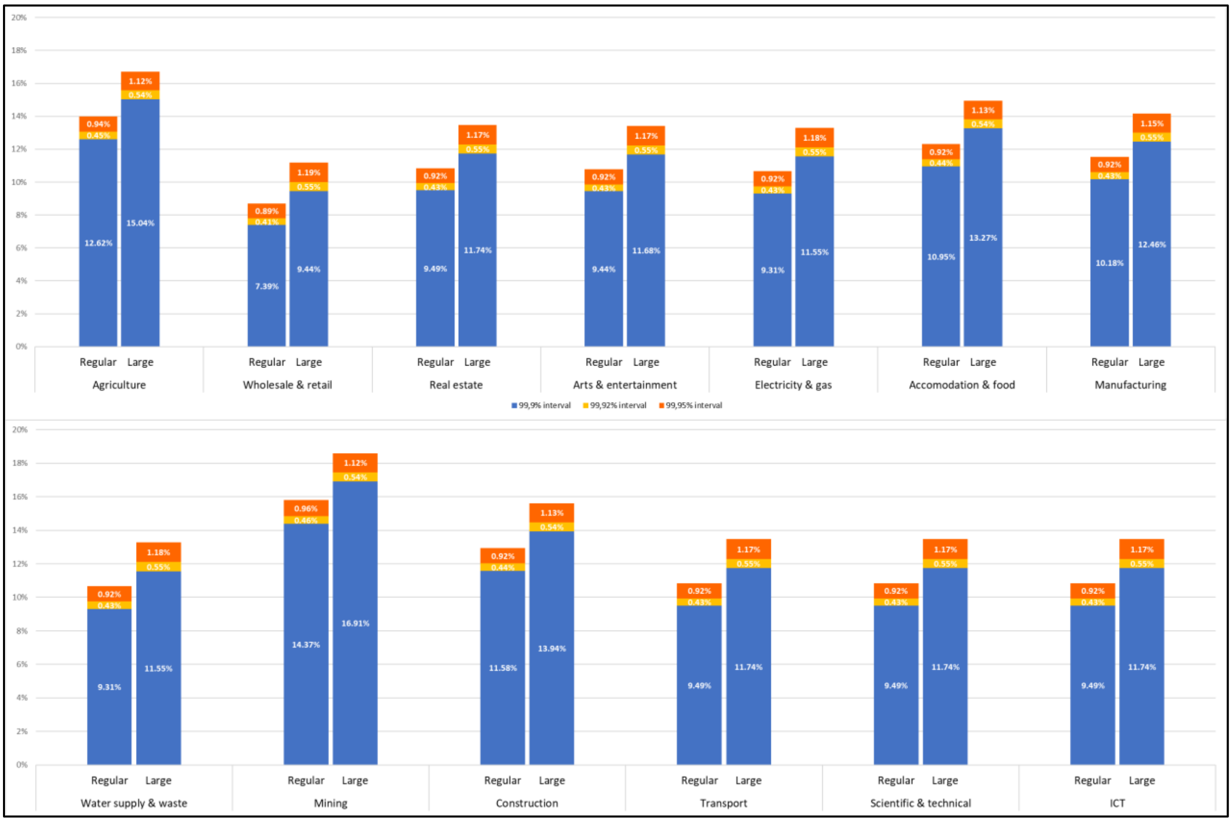
Table 5: Confidence interval parameter values

Parameter values	Normal (CI = 99.9%)
	Moderate increase (CI = 99.92%)
	High increase (CI = 99.95%)

The parameter PD will be based on the data per sector without climate stress from the European Central Bank, LGD will be maintained at 45%, as well as a maturity of 2.5 years, the minimum correlation of 12% and a maximum correlation of 24% will be also maintained.

3.5.2. Results

Figure 28: Capital requirements by sector, bank and scenario type (CI modified)



The appendix contains all the value of capital requirements, where the confidence interval has been modified (Appendix 8).

If we consider the average change in capital requirements, the incorporation of climate risk through the confidence interval (which has been changed here arbitrarily) shows a much greater variation than the incorporation of climate risk in the PDs (on average the increase in capital requirements taking into account only the climate stressed PD is 0.12% whereas the calibration of the confidence interval imply an average increase of 1.01%).

3.5.3. Level playing field

a) Particularities

- Simplicity

The adjustment of the confidence interval can help to reflect the uncertain nature of climate risk in a straightforward way, for the reason that it does not require modifying traditionally used models such as the PD and LGD model. However, it does require a robust method to estimate the uncertainty of the climate risk.

- Risk sensitivity

Although adjusting confidence intervals in the ASFR credit risk model can help to illustrate the general uncertainty associated with climate risk, it might not adequately reflect the specific impact of climate on the probability or extent of losses for individual exposures. This method might be better used as a macroeconomic tool for capturing broad climate risk, rather than for improving the risk sensitivity of capital requirements for specific exposures.

- Comparability

The uncertainty adjustment of climate would be the same for all banks.

Table 6: Summary review of the level playing field of confidence interval integration

Simplicity	High
Risk sensitivity	Low
Comparability	High

b) Context of use

Climate risk scenarios can be used to identify periods of high uncertainty. This may be particularly relevant in periods when the frequency or severity of climate-related events is increasing, or when there are significant political or technological changes related to climate change. Furthermore, if the bank does not have a robust method for estimating the increase in uncertainty due to climate risks, this approach may not be feasible.

3.6. Maturity

The maturity factor could be a way of better capturing climate risk, since climate risk is a risk that materialises more often over a longer period than traditional risks. One way of incorporating this particularity would be to increase the weight of loan length in the ASFR equation by a multiplier factor.

3.6.1. Methodology

We will multiply the maturity adjustment by using a factor and calibrate it by a sensitivity analysis. This factor will be called "F".

Our capital requirement equation will be modified as follows:

$$K = \left(\left[LGD * N\left(\frac{1}{\sqrt{1-R}}\right) - (PD) + \sqrt{\frac{R}{1-R}} * G(0.999)\right] - PD * LGD\right) * \left(\frac{1 + \left((\mathbf{F} * M) - 2.5\right) * b(PD)}{1 - 1.5 * b(PD)}\right)$$

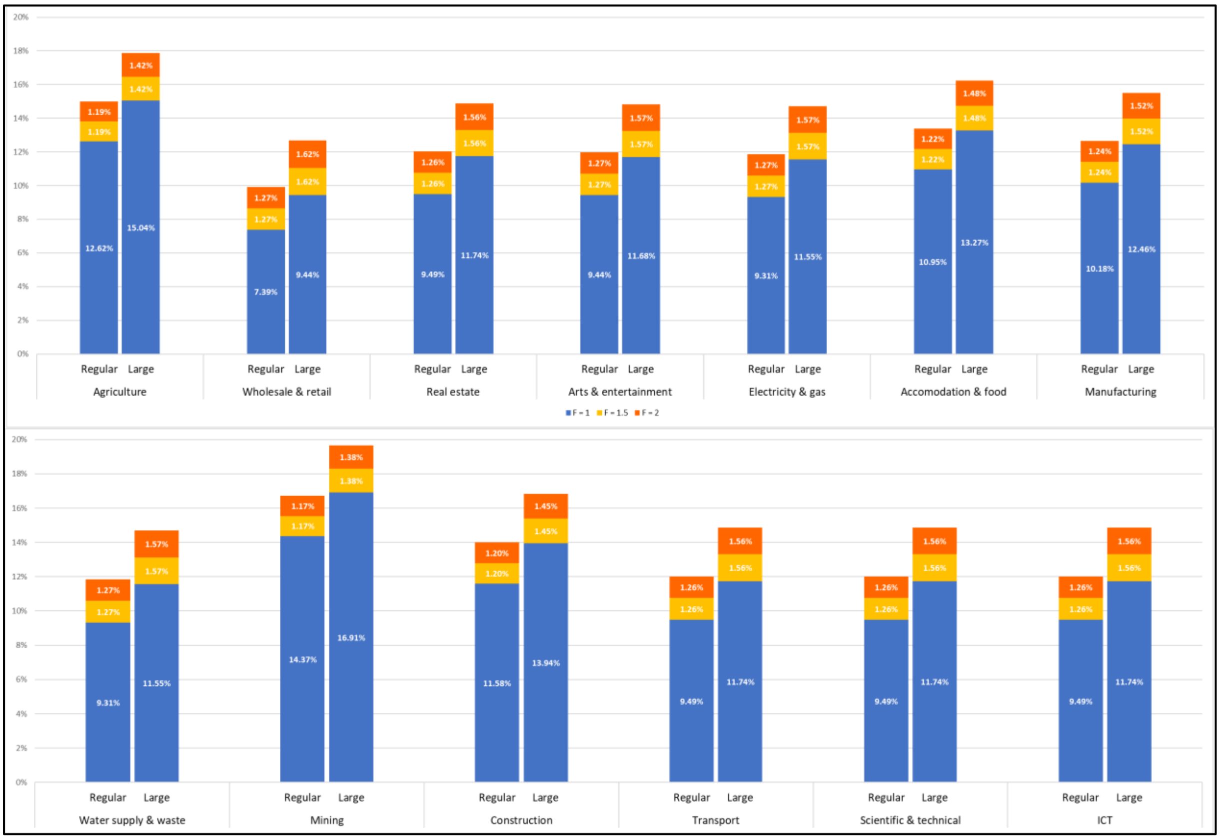
Table 7: Maturity weight parameter values

Parameter values	Normal (F=1)
	Moderate increase (F=1.5)
	High increase (F=2)

The parameter PD will be based on the data per sector without climate stress from the European Central Bank, LGD will be maintained at 45%, as well as a maturity of 2.5 years, with a minimum correlation of 12% and a maximum correlation of 24%.

3.6.2. Results

Figure 29: Capital requirements by sector, bank and scenario type (F modified)



The appendix contains all the value of capital requirements, where the maturity weight has been modified together (Appendix 9).

We can see that the values we have chosen (which were chosen arbitrarily) lead to a linear increase in capital requirements, with an amplifier of 1.5 or 2. In fact, all the "Hot house" scenarios require 2 times more increase in capital requirements than the "Disorderly Transition" scenarios.

If we consider the average change in capital requirements, the incorporation of climate risk through the mature weight (which has been changed here arbitrarily) shows a much greater variation than the incorporation of climate risk in the PDs (on average the increase in capital requirements taking into account only the climate stressed PD is 0.12% whereas the calibration of the confidence interval imply an average increase of 2.08%).

3.6.3. Level playing field

a) Particularities

- Simplicity

The calibration of the weight of maturity could be relatively straightforward, given that climate risks are long-term in nature.

- Risk sensitivity

While climate risk are long-term in nature, the maturity parameter is a pretty crude measure of the time dimension of risk and does not specifically take into account the likelihood or extent of losses.

- Comparability

The method would affect every bank in the same way and would then not affect comparability.

Table 8: Summary review of the level playing field of maturity weight integration

Simplicity	High
Risk sensitivity	Low
Comparability	High

b) Context of use

This can be useful for assets that are exposed to risks over the long term, indeed as mentioned earlier, climate risks are more likely to materialise during the asset's lifetime. This can be used in the case of macroeconomic events where it is expected that climate risks will materialise more over time (for example, if we fail to achieve our objective of being carbon neutral by 2050, we can assume that the risks will become increasingly relevant over the long term). However, the bank would need a good understanding of how climate risks evolve over the long term, indeed this calibration for short-term exposures might not be relevant.

3.7. Correlation

According to a ECB publication (Baranović et al., 2021), climate risk is concentrated by nature and increases the likelihood of climate risk becoming systemic. This concentration can be considered sectoral or regional.

3.7.1. Methodology

We will calibrate the minimum and maximum correlation parameter range by different values, using a sensitivity analysis.

Our correlation range will be modified as follows:

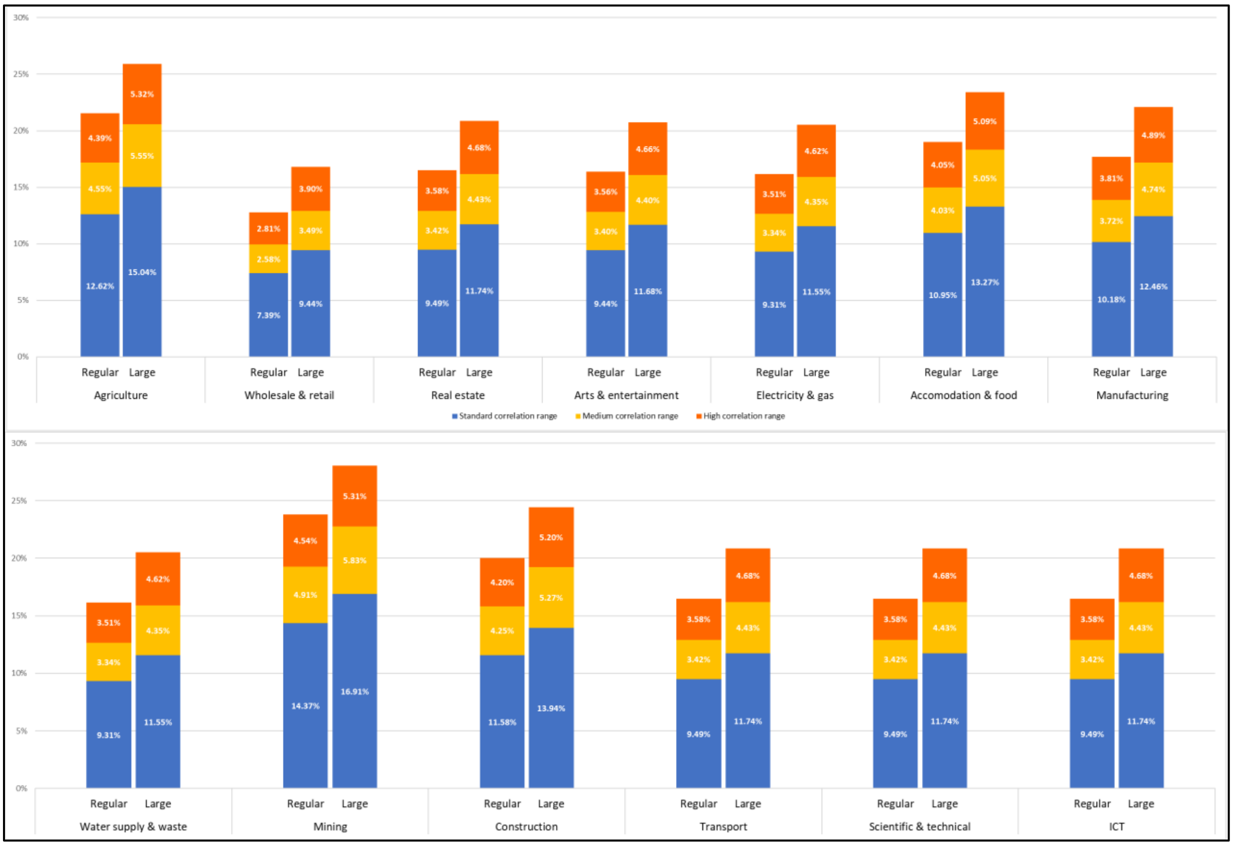
Table 9: Correlation range parameter values

Parameter values	Standard correlation range (Correlation at a minimum of 12% and maximum of 24%)
	Medium correlation range (Correlation at a minimum of 18% and maximum of 30%)
	High correlation range (Correlation at a minimum of 24% and maximum of 36%)

The parameter PD will be based on the data per sector without climate stress from the European Central Bank, LGD will be maintained at 45%, as well as a maturity of 2.5 years, and a interval of confidence of 99.9%.

3.7.2. Results

Figure 30: Capital requirements by sector, bank and scenario type (Correlation modified)



The appendix contains all the value of capital requirements, where the correlation range has been modified together (Appendix 10).

We can see that the values we have chosen (which were chosen arbitrarily) lead to a higher increase in capital requirements than the change occurred earlier by the change in PD, with an average increase in capital requirements of 6.31% (where the change in PD made earlier caused a 0.12% increase).

3.7.3. Level playing field

a) Particularities

- Simplicity

An adjustment of the correlation range could involve a complex prediction of the co-movements of losses between assets implied by climate risk.

- Risk sensitivity

As mentioned earlier, climate risk may be a systemic risk, and can then affect different assets simultaneously. The incorporation of this systemic risk can then enhance the risk sensitivity of capital requirements.

- Comparability

If banks use different methods to compute their asset correlation according to their climate risk exposure, this could affect their comparability with other banks.

Table 10: Summary review of the level playing field of correlation range integration

Simplicity	Medium
Risk sensitivity	Medium
Comparability	Medium

b) Context of use

Calibrating the correlation range can help to better capture climate risk, especially for portfolios that are highly diversified, as its specific interconnections between sectors or regions might not be consider. Also, modeling the impact of climate risks on correlation can be complex and might require data and capabilities that the bank does not possess.

IV. CONCLUSION

Numerous methods are available for integrating climate risk into the banking system, despite the particularities that distinguish it from other traditional risks. The literature reviewed in this paper allows us to discover what these particularities are, as well as the technical means available to better picture this risk in the standard processes. Researchers, regulators and central banks are among them, providing us with guidelines to follow, as well as providing insight about what the current state of the impact of climate risk is on different sectors, countries and the economy as a whole, in order to contribute to the database we have today.

This database is one of the challenges facing the bank, since apart from adapting its traditional processes, it is faced with significant challenges in terms of regime and capacity. This is where innovation comes into its own, in order to adapt processes in line with the regulatory environment and the bank's capacity.

Research into these potential solutions is essential if the bank and the system are to remain resilience in the face of global warming, which is set to intensify; at the very least, this will enable us to curb its increase and reverse the trend.

The regulatory environment for capital requirements has been analysed to see where climate risk might be included, and then supplemented with ideas outside the current regulatory context to open up the potential for adapting the latter to better include climate risk.

Following this, an analysis of the potential gaps in bank supervision that banks face in addressing this risk has been set up, as well as suggestions for improvement to help them incorporate it.

Finally, to pave the way for further research into the regulatory framework, we explored potential solutions in order to include climate risk in the Internal Ratings-Based approach, more specifically in the ASFR model, and the paper was able to discover the impact this will have on banks' capital requirements as well as the limits of these approaches through the real playing field imposed by them.

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VI. APPENDICES

Appendix 1: Standard and climate-stressed PDs

Agriculture	Normal Scenario	5.80%	Water supply & waste	Normal Scenario	2.10%
	DT Scenario	6.02%		DT Scenario	2.14%
	HH Scenario	6.29%		HH Scenario	2.18%
Wholesale & retail	Normal Scenario	1.00%	Mining	Normal Scenario	8.25%
	DT Scenario	1.03%		DT Scenario	8.49%
	HH Scenario	1.06%		HH Scenario	8.56%
Real estate	Normal Scenario	2.25%	Construction	Normal Scenario	4.50%
	DT Scenario	2.31%		DT Scenario	4.57%
	HH Scenario	2.39%		HH Scenario	4.67%
Arts & entertainment	Normal Scenario	2.20%	Transport	Normal Scenario	2.25%
	DT Scenario	2.26%		DT Scenario	2.28%
	HH Scenario	2.33%		HH Scenario	2.31%
Electricity & gas	Normal Scenario	2.10%	Scientific & technical	Normal Scenario	2.25%
	DT Scenario	2.15%		DT Scenario	2.28%
	HH Scenario	2.22%		HH Scenario	2.31%
Accommodation & food	Normal Scenario	3.75%	ICT	Normal Scenario	2.25%
	DT Scenario	3.83%		DT Scenario	2.27%
	HH Scenario	3.95%		HH Scenario	2.29%
Manufacturing	Normal Scenario	2.90%			
	DT Scenario	2.97%			
	HH Scenario	3.05%			

Appendix 2: Corresponding sector list between Figure 20 & 21

Figure 20 Standard PD Sectors	Figure 21 Relative change in PD Sectors
Real estate, scientific & administrative activities	Real estate
	Scientific & technical
Manufacturing	Manufacturing
Wholesale & retail trade, repair of motor vehicles	Wholesale & retail
Construction	Construction
Transport & storage, information & communication	Transport
	ICT
Education, health & arts	Arts & entertainment
Electricity, gas, steam & water supply	Electricity and gas
	Water supply and waste
Agriculture, forestry & fishing	Agriculture
Accommodation & food service activities	Accommodation & food
Mining & quarying	Mining

Appendix 3: Capital requirements by sector, bank and scenario types – PD modified

Agriculture	Regular bank	Normal Scenario	12.62%	Water supply & waste	Regular bank	Normal Scenario	9.31%
		DT Scenario	12.78%			DT Scenario	9.36%
		HH Scenario	13.17%			HH Scenario	9.41%
	Large bank	Normal Scenario	15.04%		Large bank	Normal Scenario	11.55%
		DT Scenario	15.22%			DT Scenario	11.60%
		HH Scenario	15.63%			HH Scenario	11.66%
Wholesale & retail	Regular bank	Normal Scenario	7.39%	Mining	Regular bank	Normal Scenario	14.37%
		DT Scenario	7.46%			DT Scenario	14.53%
		HH Scenario	7.55%			HH Scenario	14.57%
	Large bank	Normal Scenario	9.44%		Large bank	Normal Scenario	16.91%
		DT Scenario	9.52%			DT Scenario	17.08%
		HH Scenario	9.62%			HH Scenario	17.13%
Real estate	Regular bank	Normal Scenario	9.49%	Construction	Regular bank	Normal Scenario	11.58%
		DT Scenario	9.56%			DT Scenario	11.64%
		HH Scenario	9.65%			HH Scenario	11.72%
	Large bank	Normal Scenario	11.74%		Large bank	Normal Scenario	13.94%
		DT Scenario	11.82%			DT Scenario	14.00%
		HH Scenario	11.91%			HH Scenario	14.09%
Arts & entertainment	Regular bank	Normal Scenario	9.44%	Transport	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.50%			DT Scenario	9.53%
		HH Scenario	9.59%			HH Scenario	9.56%
	Large bank	Normal Scenario	11.68%		Large bank	Normal Scenario	11.74%
		DT Scenario	11.75%			DT Scenario	11.78%
		HH Scenario	11.84%			HH Scenario	11.82%
Electricity & gas	Regular bank	Normal Scenario	9.31%	Scientific & technical	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.38%			DT Scenario	9.53%
		HH Scenario	9.46%			HH Scenario	9.56%
	Large bank	Normal Scenario	11.55%		Large bank	Normal Scenario	11.74%
		DT Scenario	11.62%			DT Scenario	11.78%
		HH Scenario	11.71%			HH Scenario	11.81%
Accommodation & food	Regular bank	Normal Scenario	10.95%	ICT	Regular bank	Normal Scenario	9.49%
		DT Scenario	11.02%			DT Scenario	9.52%
		HH Scenario	11.12%			HH Scenario	9.54%
	Large bank	Normal Scenario	13.27%		Large bank	Normal Scenario	11.74%
		DT Scenario	13.35%			DT Scenario	11.77%
		HH Scenario	13.45%			HH Scenario	11.80%
Manufacturing	Regular bank	Normal Scenario	10.18%				
		DT Scenario	10.25%				
		HH Scenario	10.32%				
	Large bank	Normal Scenario	12.46%				
		DT Scenario	12.53%				
		HH Scenario	12.61%				

Appendix 4: Absolute difference by sector, bank and scenario types – PD modified

Agriculture	Regular bank	DT Scenario	0.17%	Water supply & waste	Regular bank	DT Scenario	0.05%
		HH Scenario	0.55%			HH Scenario	0.10%
	Large bank	DT Scenario	0.18%		Large bank	DT Scenario	0.05%
		HH Scenario	0.59%			HH Scenario	0.10%
Wholesale & retail	Regular bank	DT Scenario	0.07%	Mining	Regular bank	DT Scenario	0.16%
		HH Scenario	0.16%			HH Scenario	0.20%
	Large bank	DT Scenario	0.08%		Large bank	DT Scenario	0.17%
		HH Scenario	0.18%			HH Scenario	0.22%
Real estate	Regular bank	DT Scenario	0.07%	Construction	Regular bank	DT Scenario	0.06%
		HH Scenario	0.16%			HH Scenario	0.14%
	Large bank	DT Scenario	0.07%		Large bank	DT Scenario	0.06%
		HH Scenario	0.17%			HH Scenario	0.15%
Arts & entertainment	Regular bank	DT Scenario	0.06%	Transport	Regular bank	DT Scenario	0.03%
		HH Scenario	0.15%			HH Scenario	0.07%
	Large bank	DT Scenario	0.07%		Large bank	DT Scenario	0.04%
		HH Scenario	0.16%			HH Scenario	0.07%
Electricity & gas	Regular bank	DT Scenario	0.06%	Scientific & technical	Regular bank	DT Scenario	0.03%
		HH Scenario	0.14%			HH Scenario	0.07%
	Large bank	DT Scenario	0.07%		Large bank	DT Scenario	0.03%
		HH Scenario	0.15%			HH Scenario	0.07%
Accomodation & food	Regular bank	DT Scenario	0.07%	ICT	Regular bank	DT Scenario	0.02%
		HH Scenario	0.17%			HH Scenario	0.05%
	Large bank	DT Scenario	0.07%		Large bank	DT Scenario	0.02%
		HH Scenario	0.18%			HH Scenario	0.05%
Manufacturing	Regular bank	DT Scenario	0.07%				
		HH Scenario	0.14%				
	Large bank	DT Scenario	0.07%				
		HH Scenario	0.15%				

Appendix 5: Relative difference by sector, bank and scenario types – PD modified

Agriculture	Regular bank	DT Scenario	1.34%	Water supply & waste	Regular bank	DT Scenario	0.50%
		HH Scenario	4.38%			HH Scenario	1.07%
	Large bank	DT Scenario	1.20%		Large bank	DT Scenario	0.42%
		HH Scenario	3.93%			HH Scenario	0.91%
Wholesale & retail	Regular bank	DT Scenario	0.96%	Mining	Regular bank	DT Scenario	1.09%
		HH Scenario	2.19%			HH Scenario	1.42%
	Large bank	DT Scenario	0.85%		Large bank	DT Scenario	0.98%
		HH Scenario	1.95%			HH Scenario	1.28%
Real estate	Regular bank	DT Scenario	0.74%	Construction	Regular bank	DT Scenario	0.51%
		HH Scenario	1.67%			HH Scenario	1.21%
	Large bank	DT Scenario	0.63%		Large bank	DT Scenario	0.45%
		HH Scenario	1.42%			HH Scenario	1.07%
Arts & entertainment	Regular bank	DT Scenario	0.68%	Transport	Regular bank	DT Scenario	0.36%
		HH Scenario	1.63%			HH Scenario	0.74%
	Large bank	DT Scenario	0.58%		Large bank	DT Scenario	0.30%
		HH Scenario	1.39%			HH Scenario	0.63%
Electricity & gas	Regular bank	DT Scenario	0.69%	Scientific & technical	Regular bank	DT Scenario	0.34%
		HH Scenario	1.55%			HH Scenario	0.71%
	Large bank	DT Scenario	0.59%		Large bank	DT Scenario	0.29%
		HH Scenario	1.32%			HH Scenario	0.60%
Accomodation & food	Regular bank	DT Scenario	0.65%	ICT	Regular bank	DT Scenario	0.25%
		HH Scenario	1.53%			HH Scenario	0.52%
	Large bank	DT Scenario	0.56%		Large bank	DT Scenario	0.21%
		HH Scenario	1.33%			HH Scenario	0.44%
Manufacturing	Regular bank	DT Scenario	0.66%				
		HH Scenario	1.38%				
	Large bank	DT Scenario	0.56%				
		HH Scenario	1.18%				

Appendix 6: Capital requirements by sector, bank and scenario types – LGD modified

Sector	Bank	Scenario	Capital requirement
Agriculture	Regular bank	Normal Scenario	12.62%
Agriculture	Regular bank	DT Scenario	12.90%
Agriculture	Regular bank	HH Scenario	13.29%
Agriculture	Large bank	Normal Scenario	15.04%
Agriculture	Large bank	DT Scenario	15.38%
Agriculture	Large bank	HH Scenario	15.84%
Wholesale & retail	Regular bank	Normal Scenario	7.39%
Wholesale & retail	Regular bank	DT Scenario	7.55%
Wholesale & retail	Regular bank	HH Scenario	7.78%
Wholesale & retail	Large bank	Normal Scenario	9.44%
Wholesale & retail	Large bank	DT Scenario	9.65%
Wholesale & retail	Large bank	HH Scenario	9.94%
Real estate	Regular bank	Normal Scenario	9.49%
Real estate	Regular bank	DT Scenario	9.71%
Real estate	Regular bank	HH Scenario	10.00%
Real estate	Large bank	Normal Scenario	11.74%
Real estate	Large bank	DT Scenario	12.00%
Real estate	Large bank	HH Scenario	12.37%
Arts & entertainment	Regular bank	Normal Scenario	9.44%
Arts & entertainment	Regular bank	DT Scenario	9.65%
Arts & entertainment	Regular bank	HH Scenario	9.94%
Arts & entertainment	Large bank	Normal Scenario	11.68%
Arts & entertainment	Large bank	DT Scenario	11.94%
Arts & entertainment	Large bank	HH Scenario	12.30%
Electricity & gas	Regular bank	Normal Scenario	9.31%
Electricity & gas	Regular bank	DT Scenario	9.52%
Electricity & gas	Regular bank	HH Scenario	9.81%
Electricity & gas	Large bank	Normal Scenario	11.55%
Electricity & gas	Large bank	DT Scenario	11.81%
Electricity & gas	Large bank	HH Scenario	12.17%
Accommodation & food	Regular bank	Normal Scenario	10.95%
Accommodation & food	Regular bank	DT Scenario	11.20%
Accommodation & food	Regular bank	HH Scenario	11.54%
Accommodation & food	Large bank	Normal Scenario	13.27%
Accommodation & food	Large bank	DT Scenario	13.57%
Accommodation & food	Large bank	HH Scenario	13.98%
Manufacturing	Regular bank	Normal Scenario	10.18%
Manufacturing	Regular bank	DT Scenario	10.41%
Manufacturing	Regular bank	HH Scenario	10.72%
Manufacturing	Large bank	Normal Scenario	12.46%
Manufacturing	Large bank	DT Scenario	12.74%
Manufacturing	Large bank	HH Scenario	13.13%
Water supply & waste	Regular bank	Normal Scenario	9.31%
Water supply & waste	Regular bank	DT Scenario	9.52%
Water supply & waste	Regular bank	HH Scenario	9.81%
Water supply & waste	Large bank	Normal Scenario	11.55%
Water supply & waste	Large bank	DT Scenario	11.81%
Water supply & waste	Large bank	HH Scenario	12.17%
Mining	Regular bank	Normal Scenario	14.37%
Mining	Regular bank	DT Scenario	14.69%
Mining	Regular bank	HH Scenario	15.14%
Mining	Large bank	Normal Scenario	16.91%
Mining	Large bank	DT Scenario	17.29%
Mining	Large bank	HH Scenario	17.82%
Construction	Regular bank	Normal Scenario	11.58%
Construction	Regular bank	DT Scenario	11.84%
Construction	Regular bank	HH Scenario	12.20%
Construction	Large bank	Normal Scenario	13.94%
Construction	Large bank	DT Scenario	14.25%
Construction	Large bank	HH Scenario	14.68%
Transport	Regular bank	Normal Scenario	9.49%
Transport	Regular bank	DT Scenario	9.71%
Transport	Regular bank	HH Scenario	10.00%
Transport	Large bank	Normal Scenario	11.74%
Transport	Large bank	DT Scenario	12.00%
Transport	Large bank	HH Scenario	12.37%
Scientific & technical	Regular bank	Normal Scenario	9.49%
Scientific & technical	Regular bank	DT Scenario	9.71%
Scientific & technical	Regular bank	HH Scenario	10.00%
Scientific & technical	Large bank	Normal Scenario	11.74%
Scientific & technical	Large bank	DT Scenario	12.00%
Scientific & technical	Large bank	HH Scenario	12.37%
ICT	Regular bank	Normal Scenario	9.49%
ICT	Regular bank	DT Scenario	9.71%
ICT	Regular bank	HH Scenario	10.00%
ICT	Large bank	Normal Scenario	11.74%
ICT	Large bank	DT Scenario	12.00%
ICT	Large bank	HH Scenario	12.37%

Appendix 7: Capital requirements by sector, bank and scenario types – LGD x PD modified

Agriculture	Regular bank	Normal Scenario	12.62%	Water supply & waste	Regular bank	Normal Scenario	9.31%
		DT Scenario	13.07%			DT Scenario	9.57%
		HH Scenario	13.87%			HH Scenario	9.92%
	Large bank	Normal Scenario	15.04%		Large bank	Normal Scenario	11.55%
		DT Scenario	15.56%			DT Scenario	11.86%
		HH Scenario	16.47%			HH Scenario	12.28%
Wholesale & retail	Regular bank	Normal Scenario	7.39%	Mining	Regular bank	Normal Scenario	14.37%
		DT Scenario	7.62%			DT Scenario	14.85%
		HH Scenario	7.95%			HH Scenario	15.35%
	Large bank	Normal Scenario	9.44%		Large bank	Normal Scenario	16.91%
		DT Scenario	9.73%			DT Scenario	17.46%
		HH Scenario	10.13%			HH Scenario	18.04%
Real estate	Regular bank	Normal Scenario	9.49%	Construction	Regular bank	Normal Scenario	11.58%
		DT Scenario	9.78%			DT Scenario	11.90%
		HH Scenario	10.17%			HH Scenario	12.35%
	Large bank	Normal Scenario	11.74%		Large bank	Normal Scenario	13.94%
		DT Scenario	12.08%			DT Scenario	14.31%
		HH Scenario	12.54%			HH Scenario	14.84%
Arts & entertainment	Regular bank	Normal Scenario	9.44%	Transport	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.71%			DT Scenario	9.74%
		HH Scenario	10.10%			HH Scenario	10.07%
	Large bank	Normal Scenario	11.68%		Large bank	Normal Scenario	11.74%
		DT Scenario	12.01%			DT Scenario	12.04%
		HH Scenario	12.48%			HH Scenario	12.45%
Electricity & gas	Regular bank	Normal Scenario	9.31%	Scientific & technical	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.59%			DT Scenario	9.74%
		HH Scenario	9.96%			HH Scenario	10.07%
	Large bank	Normal Scenario	11.55%		Large bank	Normal Scenario	11.74%
		DT Scenario	11.88%			DT Scenario	12.04%
		HH Scenario	12.33%			HH Scenario	12.44%
Accommodation & food	Regular bank	Normal Scenario	10.95%	ICT	Regular bank	Normal Scenario	9.49%
		DT Scenario	11.27%			DT Scenario	9.73%
		HH Scenario	11.71%			HH Scenario	10.05%
	Large bank	Normal Scenario	13.27%		Large bank	Normal Scenario	11.74%
		DT Scenario	13.64%			DT Scenario	12.03%
		HH Scenario	14.17%			HH Scenario	12.42%
Manufacturing	Regular bank	Normal Scenario	10.18%				
		DT Scenario	10.47%				
		HH Scenario	10.87%				
	Large bank	Normal Scenario	12.46%				
		DT Scenario	12.81%				
		HH Scenario	13.28%				

Appendix 8: Capital requirements by sector, bank and scenario types – CI modified

Agriculture	Regular bank	Normal Scenario	12.62%
		DT Scenario	13.06%
		HH Scenario	14.00%
	Large bank	Normal Scenario	15.04%
		DT Scenario	15.58%
		HH Scenario	16.71%
Wholesale & retail	Regular bank	Normal Scenario	7.39%
		DT Scenario	7.80%
		HH Scenario	8.69%
	Large bank	Normal Scenario	9.44%
		DT Scenario	9.99%
		HH Scenario	11.18%
Real estate	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.93%
		HH Scenario	10.85%
	Large bank	Normal Scenario	11.74%
		DT Scenario	12.30%
		HH Scenario	13.47%
Arts & entertainment	Regular bank	Normal Scenario	9.44%
		DT Scenario	9.87%
		HH Scenario	10.79%
	Large bank	Normal Scenario	11.68%
		DT Scenario	12.24%
		HH Scenario	13.41%
Electricity & gas	Regular bank	Normal Scenario	9.31%
		DT Scenario	9.75%
		HH Scenario	10.67%
	Large bank	Normal Scenario	11.55%
		DT Scenario	12.11%
		HH Scenario	13.28%
Accommodation & food	Regular bank	Normal Scenario	10.95%
		DT Scenario	11.39%
		HH Scenario	12.31%
	Large bank	Normal Scenario	13.27%
		DT Scenario	13.81%
		HH Scenario	14.95%
Manufacturing	Regular bank	Normal Scenario	10.18%
		DT Scenario	10.61%
		HH Scenario	11.53%
	Large bank	Normal Scenario	12.46%
		DT Scenario	13.01%
		HH Scenario	14.16%
Water supply & waste	Regular bank	Normal Scenario	9.31%
		DT Scenario	9.75%
		HH Scenario	10.67%
	Large bank	Normal Scenario	11.55%
		DT Scenario	12.11%
		HH Scenario	13.28%
Mining	Regular bank	Normal Scenario	14.37%
		DT Scenario	14.83%
		HH Scenario	15.79%
	Large bank	Normal Scenario	16.91%
		DT Scenario	17.46%
		HH Scenario	18.58%
Construction	Regular bank	Normal Scenario	11.58%
		DT Scenario	12.02%
		HH Scenario	12.95%
	Large bank	Normal Scenario	13.94%
		DT Scenario	14.48%
		HH Scenario	15.61%
Transport	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.93%
		HH Scenario	10.85%
	Large bank	Normal Scenario	11.74%
		DT Scenario	12.30%
		HH Scenario	13.47%
Scientific & technical	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.93%
		HH Scenario	10.85%
	Large bank	Normal Scenario	11.74%
		DT Scenario	12.30%
		HH Scenario	13.47%
ICT	Regular bank	Normal Scenario	9.49%
		DT Scenario	9.93%
		HH Scenario	10.85%
	Large bank	Normal Scenario	11.74%
		DT Scenario	12.30%
		HH Scenario	13.47%

Appendix 9: Capital requirements by sector, bank and scenario types – F modified

Agriculture	Regular bank	Normal Scenario	12.62%	Water supply & waste	Regular bank	Normal Scenario	9.31%
		DT Scenario	13.80%			DT Scenario	10.58%
		HH Scenario	14.99%			HH Scenario	11.85%
	Large bank	Normal Scenario	15.04%		Large bank	Normal Scenario	11.55%
		DT Scenario	16.46%			DT Scenario	13.13%
		HH Scenario	17.87%			HH Scenario	14.70%
Wholesale & retail	Regular bank	Normal Scenario	7.39%	Mining	Regular bank	Normal Scenario	14.37%
		DT Scenario	8.65%			DT Scenario	15.54%
		HH Scenario	9.92%			HH Scenario	16.71%
	Large bank	Normal Scenario	9.44%		Large bank	Normal Scenario	16.91%
		DT Scenario	11.06%			DT Scenario	18.29%
		HH Scenario	12.68%			HH Scenario	19.67%
Real estate	Regular bank	Normal Scenario	9.49%	Construction	Regular bank	Normal Scenario	11.58%
		DT Scenario	10.76%			DT Scenario	12.79%
		HH Scenario	12.02%			HH Scenario	13.99%
	Large bank	Normal Scenario	11.74%		Large bank	Normal Scenario	13.94%
		DT Scenario	13.31%			DT Scenario	15.39%
		HH Scenario	14.87%			HH Scenario	16.84%
Arts & entertainment	Regular bank	Normal Scenario	9.44%	Transport	Regular bank	Normal Scenario	9.49%
		DT Scenario	10.70%			DT Scenario	10.76%
		HH Scenario	11.97%			HH Scenario	12.02%
	Large bank	Normal Scenario	11.68%		Large bank	Normal Scenario	11.74%
		DT Scenario	13.25%			DT Scenario	13.31%
		HH Scenario	14.82%			HH Scenario	14.87%
Electricity & gas	Regular bank	Normal Scenario	9.31%	Scientific & technical	Regular bank	Normal Scenario	9.49%
		DT Scenario	10.58%			DT Scenario	10.76%
		HH Scenario	11.85%			HH Scenario	12.02%
	Large bank	Normal Scenario	11.55%		Large bank	Normal Scenario	11.74%
		DT Scenario	13.13%			DT Scenario	13.31%
		HH Scenario	14.70%			HH Scenario	14.87%
Accommodation & food	Regular bank	Normal Scenario	10.95%	ICT	Regular bank	Normal Scenario	9.49%
		DT Scenario	12.17%			DT Scenario	10.76%
		HH Scenario	13.39%			HH Scenario	12.02%
	Large bank	Normal Scenario	13.27%		Large bank	Normal Scenario	11.74%
		DT Scenario	14.75%			DT Scenario	13.31%
		HH Scenario	16.23%			HH Scenario	14.87%
Manufacturing	Regular bank	Normal Scenario	10.18%				
		DT Scenario	11.42%				
		HH Scenario	12.66%				
	Large bank	Normal Scenario	12.46%				
		DT Scenario	13.98%				
		HH Scenario	15.50%				

Appendix 10: Capital requirements by sector, bank and scenario types – R modified

Agriculture	Regular bank	Normal Scenario	12.62%	Water supply & waste	Regular bank	Normal Scenario	9.31%
		DT Scenario	17.17%			DT Scenario	12.66%
		HH Scenario	21.56%			HH Scenario	16.17%
	Large bank	Normal Scenario	15.04%		Large bank	Normal Scenario	11.55%
		DT Scenario	20.59%			DT Scenario	15.90%
		HH Scenario	25.91%			HH Scenario	20.52%
Wholesale & retail	Regular bank	Normal Scenario	7.39%	Mining	Regular bank	Normal Scenario	14.37%
		DT Scenario	9.96%			DT Scenario	19.28%
		HH Scenario	12.77%			HH Scenario	23.82%
	Large bank	Normal Scenario	9.44%		Large bank	Normal Scenario	16.91%
		DT Scenario	12.93%			DT Scenario	22.75%
		HH Scenario	16.83%			HH Scenario	28.06%
Real estate	Regular bank	Normal Scenario	9.49%	Construction	Regular bank	Normal Scenario	11.58%
		DT Scenario	12.92%			DT Scenario	15.83%
		HH Scenario	16.49%			HH Scenario	20.04%
	Large bank	Normal Scenario	11.74%		Large bank	Normal Scenario	13.94%
		DT Scenario	16.17%			DT Scenario	19.21%
		HH Scenario	20.85%			HH Scenario	24.42%
Arts & entertainment	Regular bank	Normal Scenario	9.44%	Transport	Regular bank	Normal Scenario	9.49%
		DT Scenario	12.83%			DT Scenario	12.92%
		HH Scenario	16.39%			HH Scenario	16.49%
	Large bank	Normal Scenario	11.68%		Large bank	Normal Scenario	11.74%
		DT Scenario	16.08%			DT Scenario	16.17%
		HH Scenario	20.74%			HH Scenario	20.85%
Electricity & gas	Regular bank	Normal Scenario	9.31%	Scientific & technical	Regular bank	Normal Scenario	9.49%
		DT Scenario	12.66%			DT Scenario	12.92%
		HH Scenario	16.17%			HH Scenario	16.49%
	Large bank	Normal Scenario	11.55%		Large bank	Normal Scenario	11.74%
		DT Scenario	15.90%			DT Scenario	16.17%
		HH Scenario	20.52%			HH Scenario	20.85%
Accommodation & food	Regular bank	Normal Scenario	10.95%	ICT	Regular bank	Normal Scenario	9.49%
		DT Scenario	14.98%			DT Scenario	12.92%
		HH Scenario	19.03%			HH Scenario	16.49%
	Large bank	Normal Scenario	13.27%		Large bank	Normal Scenario	11.74%
		DT Scenario	18.32%			DT Scenario	16.17%
		HH Scenario	23.41%			HH Scenario	20.85%
Manufacturing	Regular bank	Normal Scenario	10.18%				
		DT Scenario	13.89%				
		HH Scenario	17.71%				
	Large bank	Normal Scenario	12.46%				
		DT Scenario	17.20%				
		HH Scenario	22.09%				

VII. GLOSSARY

ACPR (Autorité de Contrôle Prudentiel et de Résolution): The French Prudential Supervision and Resolution Authority.

ASFR (Asymptotic single factor risk): Simplified credit portfolio risk model design by the Basel II capital requirements.

BIS (Bank for International Settlements): International financial institution serving as a bank for central banks.

BCBS (Basel Committee on Banking Supervision): Committee of banking supervisory authorities established by the central bank governors of the Group of Ten countries.

BPF (Brown Penalizing Factor): Factor in risk assessment that penalizes environmentally harmful or "brown" investments or activities.

CCB (Capital Conservation Buffer): Mandatory capital buffer with the objective of ensuring that banks build up capital buffers outside periods of stress.

CCyB (Countercyclical Capital Buffer): Buffer that banks should hold during periods of credit growth to protect the banking sector during periods of stress.

CET1 (Common Equity Tier 1): Measure of a bank's core capital, as defined by the Basel III Accord.

CSRD (Corporate Sustainability Reporting Directive): European directive that revises and strengthens the previous guidelines for non-financial disclosures (NFRD).

DT (Disorderly Transition): Term referring to a chaotic or abrupt transition to a low-carbon economy, typically involving financial and economic instability.

EAD (Exposure at Default): EAD is a measure of the potential loss to a lender or investor in the event of default by a borrower.

EBA (European Banking Authority): Regulatory agency that works to maintain financial stability in the European Union's banking sector.

ECB (European Central Bank): The central bank for the Eurozone, responsible for monetary policy in the EU member states who have adopted the euro.

ESG (Environmental, Social, and Governance): Set of standards for a company’s operations that socially conscious investors use to screen potential investments.

ERWA (Environment Risk Weighted Asset): Measure of a bank's assets, adjusted for their environmental impact.

FED (Federal Reserve): The central bank of the United States.

FSI (Financial Stability Institute): Institute of the Bank for International Settlements that promotes cross-sectoral and cross-border supervisory contacts and cooperation.

GHG (Greenhouse Gases): Gases in the Earth's atmosphere that trap heat.

G-SIB (Global Systemically Important Bank): Banks that are too big to fail and whose failure might trigger a financial crisis.

GSF (Green Supporting Factor): Factor in risk assessment that supports or encourages environmentally friendly or "green" investments or activities.

GWF (Green Weighting Factor): Risk weight factor that adjusts the risk weighting of assets based on their environmental impact.

HH (Hot House World): Scenario by NGFS describing a future where insufficient action on climate change leads to a hotter and more unstable climate.

ICAAP (Internal Capital Adequacy Assessment Process): Process by which a bank assesses its capital adequacy based on its risk profile.

IC (Interval Confidence): Range of values, derived from a statistical analysis, that is likely to contain the value of an unknown parameter.

IEA (International Energy Agency): Organization that promotes energy security, economic growth, and environmental sustainability around the world.

ILAAP (Internal Liquidity Adequacy Assessment Process): Process by which a bank assesses its liquidity risk based on its risk profile.

IPCC (Intergovernmental Panel on Climate Change): International body for assessing the science related to climate change.

IRB (Internal Ratings-Based): Method of estimating credit risk used by banks under Basel II regulations.

KPI (Key Performance Indicator): Type of performance measurement that evaluates the success of an organization.

KRI (Key Risk Indicator): Measure used by an organization to monitor the level of risk it is facing.

LGD (Loss Given Default): The amount of money a bank or other financial institution loses when a borrower defaults on a loan.

NACE (Nomenclature des Activités Économiques dans la Communauté Européenne): Statistical Classification of Economic Activities in the European Community

NFRD (Non-Financial Reporting Directive): EU directive that requires certain large companies to include non-financial information in their annual reports.

NGFS (Network for Greening the Financial System): Network of central banks and supervisors aiming to mobilize the financial system to respond to climate change.

OECD (Organisation for Economic Co-operation and Development): International organisation that works to build better policies for better lives.

PD (Probability of Default): The likelihood that a loan will not be repaid and will fall into default.

PRA (Prudential Regulation Authority): UK regulatory body responsible for the prudential regulation and supervision of banks, building societies, credit unions, insurers and major investment firms.

RWA (Risk-Weighted Assets): Measure of a bank's assets, adjusted for their associated risks.

SA (Standardized Approach): Set of procedures for evaluating banking activities, and the resulting capital requirements, prescribed by the Basel II Accord.

SREP (Supervisory Review and Evaluation Process): Process conducted by the supervisory authorities to review and evaluate the risks of an institution.

SyRB (Systemic Risk Buffer): Capital buffer that member states can require their banks to hold to prevent and mitigate long term non-cyclical systemic or macroprudential risk.

TFCD (Task Force on Climate-related Financial Disclosures): Task force established by the Financial Stability Board to develop voluntary climate-related financial risk disclosures.

Tier 1 capital: The core measure of a bank's financial strength from a regulator's point of view.

VaR (Value at Risk): Measure of the risk of loss for investments.

WEF (World Economic Forum): International organization for public-private cooperation**.**

The impact of climate change is increasingly being witnessed by society. The challenge of taking climate risk into account in the financial system is becoming crucial to achieve an effective, sustainable and fair transition for all.

In this thesis, we delve into the unique attributes of climate risk that set it apart from traditional financial risks. This examination leads to a particular integration of climate risk within the taxonomy and risk management processes. This is followed by the integration of climate risk into the regulatory capital and bank supervision set today, but also to proposals outside the current regulatory framework, which add new perspectives of this integration.

Finally, we will empirically observe the impact of the integration of climate risk into Basel's Internal Ratings-Based approach for credit risk, being the so-called Asymptotic Single Risk Factor (ASRF) model, with its potential use in the matter and limitations.

UNIVERSITÉ CATHOLIQUE DE LOUVAIN

Louvain School of Management

Place des Doyens, 1 bte L2.01.01, 1348 Louvain-la-Neuve

Boulevard Emile Devreux 6, 6000 Charleroi, Belgique

Chaussée de Binche 151, 7000 Mons, Belgique

www.uclouvain.be/lsm