IMPACT OF CLIMATE TRANSITION RISK ON THE CREDIT PROFILE OF SMEs

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Master Thesis

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Abstract

Climate change is an intensively growing problem which is forcing to increase actions to reduce greenhouse gas emissions, the main drivers of climate change. Beyond well-known climate effects, spillover effects could also have a large impact on the global economy and financial system. Climate risk in risk management and supervision is divided into two types depending on their way of materializing: physical risks and transition risks. The former comes from the effects of extreme climate-related events, while the latter focuses on the arisen turbulences from the transition towards a low-carbon economy. The aim of this paper is to analyze the impact of climate risk on a financial institution's credit risk. We rely on a recent technical report of the Bank of Canada to study the effect of transition risk on a portfolio of SMEs in the Spanish market, differentiated by sectors. A combination of top-down and bottom-up approaches is used to calculate changes in the Probability of Default (PD) and Loss Given Default (LGD) under different feasible climate scenarios. We consider a shifted Merton model to project the PDs and the Frye-Jacobs relationship to estimate the LGDs. The results obtained are similar to those reported by the BoC, although crops sector show greater impact. More specificaly, the results show that in the long-term the most damaged sectors are crops, refined oil products and oil & gas, while the most resilient ones are electricity and commercial transportation. In general, the Below 2°C Delayed and Net-Zero 2050 scenarios imply a higher impact on credit risk.

Keywords: climate change, climate risk, transition risk, climate scenario, probability of default, loss given default, Merton model, Frye-Jacobs relationship.

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Chapter 1

Introduction

The last decade has seen large effects of climate change due to the increase of greenhouse gas (GHG) emissions resulting from human activities. If greenhouse emissions were not mitigated, global warming would continue to grow, which could cause very severe and irreversible consequences for the planet. Nowadays, the Intergovernmental Panel on Climate Change (IPCC) [1] estimates that the temperature is 1.1°C warmer than it was in the pre-industrial stage in the late 1800s as a result of the constant growth of GHG emissions and that global temperature rises about 0.2°C every decade.

It is estimated that global warming would reach 3.2°C by the end of the century if no further actions were taken. To avoid this trend the United Nations Framework Convention on Climate Change (UNFCC) adopted in 2015 The Paris Agreement, a legally binding international treat on climate change whose aim is to limit global warming to below 2°C or preferably to 1.5°C compared to the pre-industrial stage (see UNFCCC [41]).

Nearly 200 countries take part in The Paris Agreement by communicating economic and social actions, both individual and coordinated, they will take to reduce their greenhouse gas emissions in line with the agrement's goals. This is a process that everybody, including all economic agents, should take part on in order to have a successful transition towards a low carbon economy. It is necessary that advanced economies support emerging economies in mitigating and adapting to climate change by providing them with the essential resources and technology needed to transition without limiting the economic development. Governments also play an especially important part on the low carbon transition. It is essential for them to implement policies that help to mitigate the emissions and the impacts of climate change

[1] "The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change" (Website).

1.1 Climate change in finance and types of climate risks.

Climate change can have a great impact on worldwide economy growth through all sectors such as production, services, transportation and so on, including the financial system. Especially, financial institutions have a crucial role in the climate transition because financial markets are key instruments for boosting the mitigation of climate risk. Climate risks refer to financial risks generated by the exposure of institutions to entities that may contribute to or be affected by climate change.

The financial sector is specially relevant for the transition towards a low carbon economy because they are not only exposed to climage change in their activities, but also they could, by means of their activity, make a difference in the transition trend. For instance, they are exposed to climate risks arising from the deterioration of the collateral of borrower firms caused by extreme climate events. Nevertheless, they could also decide the firms which would receive the loan. So, by boosting the loans to low-carbon firms, they could help to reduce emissions and make more feasible a smooth transition towards a low carbon economy.

This double effect that covers not only climate-related impacts on the firm's activities but also the impacts of firm's activities on climate change is the so called "double materiality" (see Figure 1.1 and Täger, M., 2021 [39]). This new concept implies a change in the criteria of the finanial entities for giving credit. On the one hand, they seek to reduce the bank's exposure to the effect of climate change and, on the other hand, they reduce the financing to activities that may involve and speed climate change.

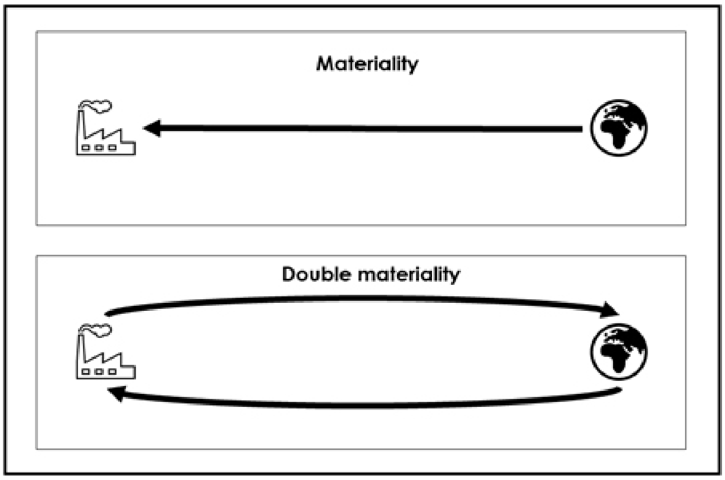

Figure 1.1: Graphic comparison between "Materiality" and "Double materiality". (*Source: London School of Economics*)

One way financial institutions can contribute to the reduction on emissions is redirecting their investments into greener projects avoiding “brown” investments or emission-intensive firms. Currently, there are available “green bonds” and “climate aware” mutual funds that financial institutions should support and prioritize by investing in them. “Green bonds” are fixed-income instruments which are used to support and finance projects that are respectful to the environment, for instance, renewable energies or clean transport. Investors are increasingly investing into “greener” activities that are not significantly contributing to climate change. However, an activity that is not green is not necessarily harmful to the environment (see Alessi, L. and Battiston, S. (2021)[2]).

Nevertheless, banks should not completely stop investing in “brown” sectors or companies. Instead, they should finance the transition of these companies towards a more sustainable production and reward their effort to mitigate these risks. Because even if high-carbon sectors are riskier for the transition, those are precisely the sector that need more massive and urgent financing for the transition. That is why banks can play an extremely influential and impactful role in the transition to a greener environment.

An important question that arises from the strong involvement of the financial sector is whether their contribution to reduce emissions is more significant by reducing credit to "brown" firms or financing their transition towards a greener activity. Results suggest that reallocating credit into a greener portfolio contributes more to the reduction of emissions of the firms (see Kacperczyk, M. and Peydró, J.-L., 2021 [29]).

Authorities consider climate change as an emerging threat to the financial stability given that it is expected to be a significant issue our society will have to face for many years to come (see Banco de España, 2019 [8]). That is why climate risk, a new and quickly growing type of aggregate risk, recently become relevant to the financial sector. Because of its novelty, this risk does not have a standardized approach yet. There is still a lot of work to do trying to understand and manage it. Unlike the known financial risks, climate risks face new challenges.

Climate risks are expected to have effects in the medium to long-term and evolve over decades (30-100 years) while portfolios are usually managed in the short term. Moreover, climate events’ distribution is highly non-linear and historical data is not very representative of the analysis horizon. Instead, climate risks are endogenous because the evolution of the climate events depends on the agents’ perception and reactions, but at the same time, these beliefs and decisions depend on the materialization of climate events. So, there is great uncertainty and limited information, which leads to the need to consider a wide range of feasible scenarios that are complex and vary across sectors and geographies. In order to have successful advances, a considerable coordination between organizations and a methodology that is repeatable, standardized and consistent, but customizable for different scenarios, sectors and geographies is required.

There is much uncertainty as to whether climate risks should be considered in risk management, supervision and regulation of banks and how to introduce them. Climate risk is highly correlated across institutions, which makes failure contagion and interconnectedness between financial institutions elevated. There are a few sources of risk propagation within the economy, for example, input-output interdependencies of economic activities. So, a materialization of a climate event could have direct impacts on several financial firms, leading potentially to disruptions in financial stability. Exposure to climate change could affect to banks' contribution and exposure to systemic risk (see Aevoae G.-M. *et al.*, 2022 [1]). Therefore, climate risk assessment should combine individual risks with interactions among economic and financial institutions.

Currently there are two main types of climate risks that do not usually materialize at the same time. Physical risks are derived from a gradual and long-term global warming or the increasing severity and frequency of extreme weather event. They can affect directly to the entity's assets and infrastructures or indirectly by harming its operations and activities. Transition risks cover a wide range of effects of transitioning towards a low emission environment: disorderly or abrupt policy implementation such as limiting emissions or taxing carbon, technological innovations, changes in the preferences of investors into greener options etc. For example, coal, gas and oil reserves could suddenly be devaluated due to a decrease in demand and changes in the customer preferences.

Disorderly and sudden policies could significantly increase stranded assets. The number of stranded assets caused by environmental factors is increasing significantly in the recent years. Thus, Climate risks could lead to stranding entire regions and global industries within a short period of time. These could have severe impacts, both direct and indirect, on investment strategies and liabilities (see Caldecott B. *et al.*, 2017 [14]).

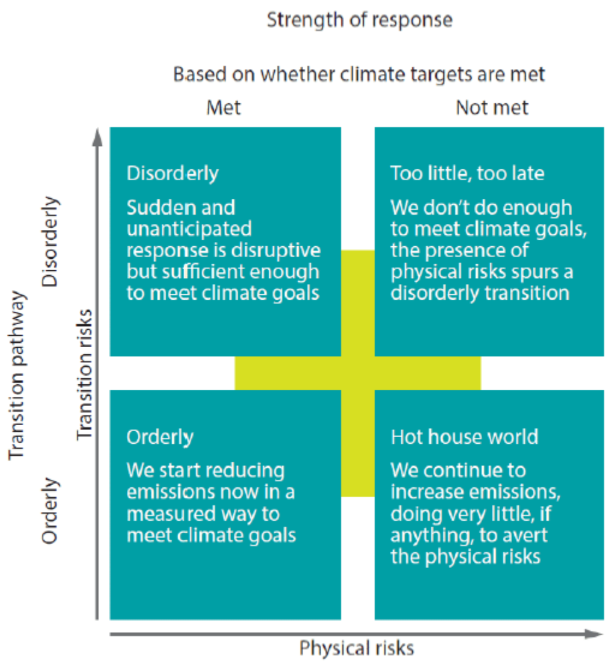

Figure 1.2: Different climate evolutions depending on the combinations of transition risks and physical risks. (*Source: NGFS, June 2020* [31])

Physical risks and transition risks are correlated and usually move in the opposite direction. The magnitude of each kind of risk depends on the speed and timing of public policy actions and the development of new technologies, among others. So, transition and physical risks can be combined in different ways so that we find different possible climate evolutions (see Figure 1.2):

- In an orderly transition immediate policies with a high level of international coordination are implemented, which gradually decreases emissions and relatively mitigates both types of risk, physical and transition.
- If the policies and measures are disorderly o belatedly implemented but effective, there would be unexpected damages and financial impacts that would trigger negligible physical risks and large transition risks.
- If the climate policies are not properly implemented in the disorderly transition, both physical and transition risks could be considerably high.
- If no policies or measures are implemented or if they are introduced very slowly, the transition risks would be manageable, but physical risk would be very high. This evolution is known as “Hot house world”, where global warming is expected to exceed 3°C.

Considering the possible combinations of physical and transition risks, The Network of Central Banks and Supervisors for Greening the Financial System (NGFS) [2] designed more specific and granular scenarios. They created six hypothetical scenarios with help from an expert group of climate scientists and economists.

There are many ways of achieving below 2°C that could impact the economy differently depending on the underlying technology since there is great uncertainty as to which technologies might lead the environmental transition in the future. The scenarios designed by the NGFS provide 6 hypothetical but plausible evolutions of climate change based on different assumptions that are consistent with achieving global climate targets. The scenarios consider interactions between policies, technology and economic sectors.

Scenarios are not predictions or forecasts of what will happen. They are designed to show different risk outcomes and cover a wide range of feasible physical and transition risks. The scenarios consider two main key drivers that are ambition and timing of climate policy; and pace of technological change and availability of Carbon Dioxide Removals (CDR) [3]. In the paper we focus on four of the six scenarios designed:

[2] NGFS is a group of Central Banks and Supervisors with voluntary basis launched in December of 2017. The main purpose of the group is to contribute to the development of environment and climate risk management in the financial sector by sharing best practices and new discoveries. They also try to boost finance that backs the transition toward a more sustainable economy. They suggest to publicly share data and collaborate with different institutions with transparency to overcome the important lack of data.

[3] CDR is a process in which CO_2 is removed from the atmosphere and sequestered for long periods of time.

- Current Policies: Currently implemented policies are preserved and no new policies are implemented, technology change is slow and there is a low use of CDRs. This leads to high physical risks where emissions keep growing and global warming reaches up to 3°C. Irreversible changes are caused with mainly long-term impact. This scenario is usually used as a baseline scenario where there is no transition risk and we can see what could happen if we continue our current path.

- Below 2°C or Below 2°C Immediate: Climate policies are immediately and gradually implemented, becoming smoothly more stringent. There is a great chance of limiting global warming to below 2°C by 2100. There is a moderate technology change and a medium use of CDRs. It is expected to reach net-zero in 2070. Both physical and transition risks are manageable.

- Net-Zero 2050: Introduces ambitious and strict climate policies immediately aiming to reach net-zero emissions by 2050 and limit global warming to 1.5°C. There is a fast technological change and a medium use of CDRs that accelerate the mitigation of emissions. Transition risks are really high but physical risks are reduced considerably.

- Delayed Transition or Below 2°C Delayed: New climate policies are not implemented until 2030 and differ across countries and regions. Moreover, CDR technologies are not highly available. In order to reach the aim of limiting global warming to 2°C, sharper policies have to be implemented, such as higher carbon prices. Both transition and physical risk could be high.

In order to boost a low-carbon transition, it is necessary for governments to take actions and implement policies. Those policies require a continuous evaluation to achieve the proposed environmental objectives without wasting resources and avoid unwanted effects. Transition scenarios are also used by policymakers to analyze how the implementation of some policies might evolve. The lower the temperature target is, the more aggressive policies will be required.

One of the most effective policies implemented is increasing the price of carbon and environmental taxes. This would lead to significant increases in costs for firms that have high scope 1 emissions, but also for firms with high scope 2 and scope 3 emissions for example through increases in input prices. Increasing the costs could cause firms trying to mitigate their greenhouse gas emissions to avoid the emission costs and supply customers that have greener preferences. The speed of mitigation of gas emissions depends on the timing of the policies.

The main difference between the Delayed transition and Below 2°C scenarios is that in the first one no policies are implemented until 2030. The longer it takes to implement the policies to transition towards a low CO2 consumption economy, the more aggressive the measures have to be. That increases their negative impact by concentrating in a shorter period of time and increases the risk of transition. It can be seen in Figure 1.3 that for the Delayed transition scenario to reach the same target as the Below 2°C scenario, a sharper increase in the carbon price would be needed for the emissions to fall rapidly from 2030 forward and make up the lost time. In the Current policies scenario or Hot house word scenario, not new policies would be implemented. Hence, carbon price would not increase much and emissions would keep growing significantly.

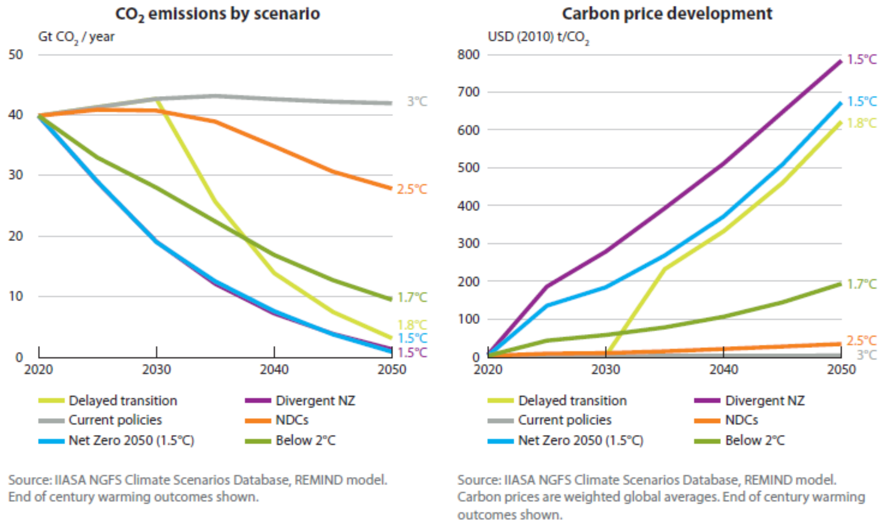

Figure 1.3: Evolution of GHG and carbon emissions and their price in different scenarios until 2050. (*Source: NGFS, 2021 [32]*)

1.2 Impact of climate risk on credit risk.

Climate risk can affect the financial system through a range of different transmission channels, for example, credit risk. Therefore, climate risks can impact the valuation of firm-level assets and firms' creditwothiness. The exposure to each type of climate risk depends on the asset. For example, buildings located near the sea or in wildfire-prone areas are more exposed to physical risks, while loans to emission intensive sectors such as fossil fuel companies are more exposed to transition risk.

In order to manage the impacts on financial risks (for example, credit risk, market risk, liquidity risk, reputational risk or operational risk), it is useful to disentangle the potential interactions between climate change and financial markets (Giglio S. *et al.*, 2020 [24]). The main uncertainties about these interactions refer to the future evolution of climate and economic activity. Lately, there has been an important progress in studying how climate change affects different types of assets. For instance, Lucas ter Steege and Edgar Vogel (2021)[38] study how real estate prices decrease when they are allocated in a physical risky location and how transition risks can also devaluate collaterals. Faella I. *et al.* (2021) [21] show that an abrupt transition to a low-carbon economy could lead to sudden asset repricing that could end up losing value.

In this work, we will concentrate on the impact of the climate risk on the credit risk for the banking system. Impacts on credit risks will be measured as changes in probability of default (PD) and loss given default (LGD) on the loan books.

PD is the likelihood of a borrower not paying back a debt. In case of default, LGD is the amount of money the financial institution losses taking into account any recovery it might have in that case and measures the severity of the default. LGD varies depending on the collateral provided and the value of the asset on the time of default. One of the main challenges of climate risk that we will try to overcome in this assignment is precisely how to measure the change in PD and LGD under different climate events. Once PD and LGD changes are measured, it is possible to estimate another important credit risk metric that is the Expected Credit Loss (ECL). ECL is the amount that the bank expects to lose on its lending exposure and can be calculated as seen i Equation 1.1. EAD is the Exposure at Default that represents the financial exposure to the borrower at the time of default.

$$ECL = PD * LGD * EAD \tag{1.1}$$

1.3 Climate risk impact on SMEs.

SMEs are a key part of the global economy (see OECD, 2017 [34]). 99% of all businesses in the European Union are SMEs, that is, they are the predominant form of enterprise in the EU. That is why we consider of great interest to study the effect of climate risk on the SME's credit risk. First, about 90% of the balance sheet of many financial institutions are SMEs since, unlike large enterprises, SMEs have trouble obtaining wholesale financing. Second, the participation of SMEs can be crucial in the transition towards a more sustainable economy thanks to their new ideas, products and services. Third, SMEs usually have fewer requirements and reduced fees, but they are more vulnerable to market failures and they are less prepared for the climate challenges due to the lack of resources to evaluate the impact.

Therefore, it is a key challenge to work with SMEs and design a methodology to analyze them. Working with SMEs has its difficulties such as significant lack of data or great need of estimations that vary widely across entities.

SMEs are not listed on the market, so there is some information they are not mandated to disclose and it can be difficult to find available data about them. The assessment of climate risk relies highly on the availability of high-quality and reliable data. Large firm that are listed on the market are individually analyzed and there is a wide range of data available in platforms such as Moody's, S&P, etc., including climate related information (for example, ESG ratings or emission data). Even if the information available for large enterprises is more extensive than for SMEs, not all the information desirable is known. However, the increased demand by institutional and private investors for sustainable finance and legal obligations in the EU is soon going to require for large firms to disclose on the greenness of their activities. So, data quality and availability are expected to improve in the next years.

Lack of resources such as management capacities, skills, knowledge or finance, makes it difficult for SMEs to access ratings and evaluations of greeness. Hence, a lot of SMEs cannot afford to generate climate data. Our work provides a possible framework approach to apply in those cases.

The rest of the paper is organized as follows. Chapter 2 describes the methodology followed in the empirical exercise. Chapter 3 accounts for the data description and collects the empirical results obtained. Finally, Chapter 5 concludes and discusses results and further research. Supplementary material is provided in the Appendixes.

Chapter 2

Methodology

2.1 Climate stress test.

In this paper, we carry out a climate stress test with the aim of quantifying the impact of transition risks on the credit risk of a portfolio of SMEs. Climate stress tests are now commonly used to assess relations between changes in climate-related factors and changes in the riskiness of exposures. We consider Current Policy scenario as a baseline, where we assume that there is no transition risk, and we analyze the impact on 3 adverse scenarios (Below 2°C Delayed, Below 2°C Immediate and Net-Zero 2050) as shocks in the credit risk relative to the baseline.

In December 2016 the Task Force on Climate-related Financial Disclosures (TCFD) was formed with the aim of recommending ways of measuring the risks and opportunities derived from climate change. The TCFD tries to find ways of managing climate risks based on transparency and communications.

Following the recommendations of the TCFD, many Central Banks and supervisors have begun to share their stress tests and the results. For example, the European Central Bank (ECB) designed a climate event stress test in 2022 for the first time (see European Central Bank, 2021 [18]). The Bank of Canada (BoC) also shared their stress tests and results in Hossini, H. *et al.* (2022) [26] which we use as a basis for this paper.

Scenario analysis and transition risk assessments can be approach in different ways: top-down (macro-economic level or sector-level) or bottom-up. The top-down approach begins at the general and goes to the specific. On the contrary, the bottom-up approach moves from the specific to the general. The main ideas and differences of each of the approaches are collected in BOX 2 of Colas, J. *et al.* (2018) [17].

One way of overcoming the difficulties of each approach could be using a mix of sector-level and borrow-level modelling to capture climate risk, which is exactly what we apply in this paper.

For a better understanding, a generic financial climate transition risk assessment tool is shown in Figure 2.1. In that case, a top-down deterministic approach was considered, but for a bottom-up approach, it would be enough to skip the macroeconomic model. The tool is based in climate scenarios that provide different emission trajectories depending on the decisions made and aims of limiting global warming. The outputs from the climate scenarios are translated into macroeconomic changes in the economic impact analysis. Based on the economic activity analysis, a firm-level impact analysis is made by calculating changes in revenues, costs and associated profit and cash-flow variations (for bottom-up tools we consider the outputs from the climate scenarios directly as input in this analysis). Finally, firm-level economic impacts are used to calculate climate-adjusted financial performance indicator by a financial impact analysis.

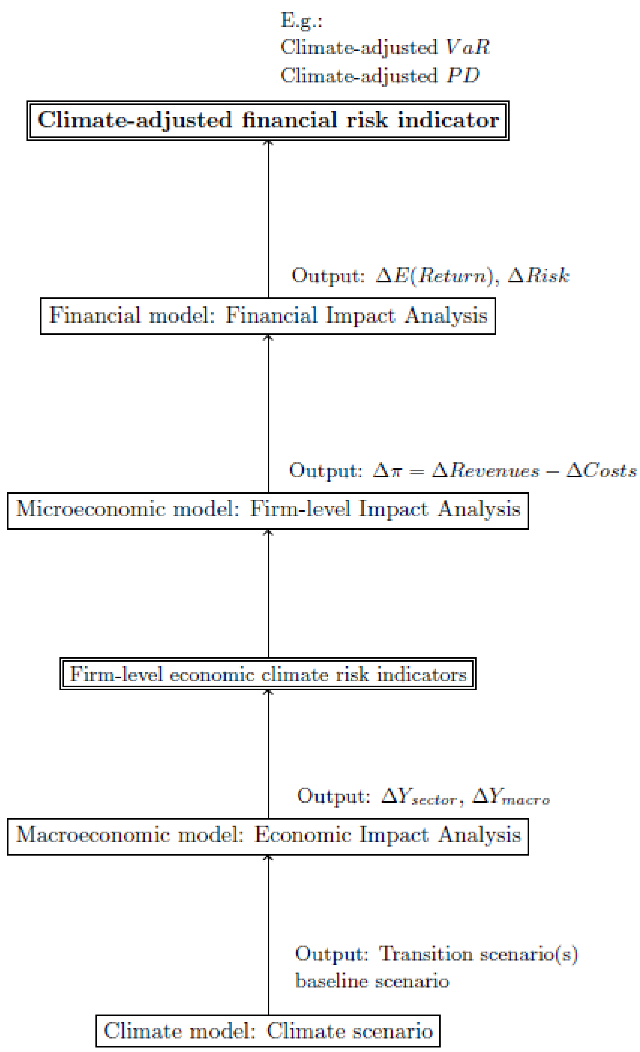

Figure 2.1: Generic financial climate transition risk assessment tool with a top-down deterministic approach. (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

In this investigation, our aim is to analyze the impact of climate risk in credit risk, so our main interest risk indicators will be Climate-adjusted PD and Climate-adjusted LGD.

2.2 Climate models.

Incorporating climate risks in risk management raises new challenges since financial entities' current economic models were not designed to consider the effects of climate risks. Usually, evaluating the economic impact of climate change relies on Integrated Assessment Models (IAMs), CGE models, etc. (see Appendix 1 of Ens, E. and Johnston, C., 2020 [20]). These models try to explain interactions between economic variables, such as GDP or returns by sectors, and climate impacts over the long term. As these models provide with a valuable insight of climate-economy links, they are extensively used for example to support governments' climate policies.

A rapidly growing number of market participants and financial authorities' research with a lack of agreement, creates a wide range of methodologies related to climate risks that could differ remarkably. The Swiss Federal Institute of Technology Zurich (ETS) tried to collect and share different climate models that translate climate scenarios into economic and financial impacts (see Bingler, J. A. and Colesanti Senni, C., 2020 [11]). They perform an in-depth descriptive and criteria-based analysis of 16 existing climate models (see Appendix A).

Each model provides us with different financial and economic metrics that capture climate risks. It is of interest that the results of different models do not differ much. Different transition risk metrics usually agree on the most and least exposed firms. Moreover, for the firms most exposed to transition risk, risk metrics tend to have significantly higher convergence (see Bingler, J. A. *et al.* [12], 2021).

Knowing that different models lead us to a similar identification of the firms most exposed to climate risk, we will use the results obtained by applying the climate model MIT-EPPA designed by the Bank of Canada (see Chen, Y.-H. H., 2022 [16]). MIT-EPPA is a multi-region and multi-sector recursive dynamic equilibrium model of world energy and economy. So, it models the economy as an optimization problem where firms make cost-minimizing decisions. The problem is solved through a large non-linear program which is subject to a set of conditions: i) Market clearance: supply equals demand; ii) Normal profit: The costs of inputs are lower than the price of the output; and iii) Income balance: Expenditures equal income considering savings, subsidies and taxes. The main risk indicators of the model are economic variables and emissions of greenhouse gases and other air pollutants, growth in population, and the economic activity.

The model has a great coverage of risk sources. Considers different types of policies such as emission limits, carbon taxes, energy taxes, etc. It also contemplates interactions among households, firms and the government. Unlike most of the models captured in Appendix A, takes into consideration links between sectors, such as relations through supply chains, to evaluate the propagation of policies throughout the economy, or connections through competition across sectors, to evaluate the possible substitution among inputs. MIT-EPPA also covers technological changes, for example the introduction of new energies or changes on the cost of advanced technologies.

The main objective of the model is to assess the impacts on credit and market risk of portfolios under certain transition scenarios. Aligning with the scenarios designed by NGFS, the model considers 4 of the scenarios describe previously: Current Policies, Below 2°C, Delayed Transition and Net zero 2050. For each scenario, sector and country several economic output metrics are estimated for a time horizon of 30 years (until 2050), such as output price, input costs, carbon price, capital price, production, scope 1 emissions, inputs in production, new capital added, etc. The model does not impose an exogenous path of carbon prices, instead has the purpose to reduce emissions by a pre-determined amount.

The outputs of the transition scenario model describe the policies, technology and market impacts on each scenario. However, we need to interpret them financially. Based on the estimated outputs, it is possible to calculate four components that summarize the performance and describe the financial losses and gains for corporates within a sector and a country. These components can be calculated for every sector and scenario, so a comparison across them is possible. The four components are:

- Direct emissions costs = carbon price * scope 1 emissions. Reflects changes in the costs associated with the direct greenhouse gas emissions of the sector.
- Indirect costs = input price * inputs in production. Captures changes in input costs on the supply chain due to upstream sectors passing on their changes in direct emission costs.
- Capital expenditures = capital price * new capital added. Reflects the changes in the capital needed by the sector to face the transition and become more efficient, for example increases to purchase new technologies that reduce the sector's emissions and meet energy efficiency mandates.
- Revenues = output price * production. Captures fluctuations in the demand of the sector due to increases in prices and changes in the preferences of the consumers that purchase less products that remain emission-intensive; changes in additional taxes and subsidies; etc.

Combining the components, the net income can be estimated: Net income = Revenues - (Direct emissions costs + Indirect costs + Capital expenditures). The net income allows us to see the financial impact on each sector as a whole associated with the transition scenarios.

In the same way, we can map four Risk Factor Pathways (RFPs) that reflect changes on the each of the components relative to the Current Policy scenario. The RFPs will be the drivers of changes in PDs and LGDs. In the paper, we analyze the impact of transition risk on credit risk. Since in the Current Policy Scenario no more policies are implemented, all the credit risk changes will be driven by physical risks or other effects, but not by transition risks. So we consider Current Policy scenario as the baseline scenario and we supposed that transition risks have no impact on credit risk. For the rest of the scenarios, we will consider RFPs relative to the baseline scenario.

2.3 Methodology of the empirical exercise.

The methodology followed in this paper is based on the methodology carried out by the Bank of Canada (see Hossini, H. *et al.*, 2022 [26]) and proposed by the Task Force on Climate-Related Financial Disclosures (TCFD) (see Colas, J. *et al.*, 2018 [17]). The TCFD gave recommendations and guidance to do a forward-looking climate scenario-based stress testing. It is a methodology that combines sector-level top-down and borrower-level bottom-up approaches in order to try to take advantage of the strengths and overcome the disadvantages of each of the approaches. The methodology focuses on the impact of transition risks on the entity's credit risk in a horizon of 30 years in 5-year steps. We analyzed how transition risks affect the credit profile of the borrowers, and therefore, the risk of the loan portfolio.

To carry out a climate stress test we need to quantify climate risks under different scenarios. For non-financial borrowers climate risks can be quantified through the impact of climate-related factors on financial metrics such as incomes, profits, costs or damages. This impact is then translated into financial institutions' credit risks. For these purposes, the BoC provides geographic and sector level economic and financial data (website). The scenario variables provided include production, carbon price, input prices, output price, emissions intensities, investment needs, etc., and also the 4 components needed to calculate the RFPs (direct emission costs, indirect costs, capital expenditure and revenues) for the period between 2020 and 2050 with 5-year time steps under 4 scenarios (Current policies, Below 2°C, Delayed transition and Net-zero 2050). The variables were estimated by the model MIT-EPPA explained in Section 2.2.

Given the four components provided, the RFPs, that is, changes in the components relative to the baseline scenario, can be calculated. These RFPs are differentiated by sectors and countries/regions since the impact of the transition scenarios is not the same for all sectors and geographic location. There are many transition risk drivers that differ according to the sector and country. Some sectors or countries may have a negative impact while others may have positive impact. Countries that depend a lot on high emissions-intensive sectors would be more harmed that the ones with more renewable technologies and less emissions. The exposure to transition risks is not the same for all sectors because their possibilities and capacities to deal with transition risks is not the same. We consider data corresponding to all the sectors provided for Europe, where

Laboral Kutxa is located and conducts its business. In addition, to begin with, we consider that the entity's balance sheet is static in the analyzed horizon, although it is not very realistic.

Once we have the 4 RFPs, the steps we need to follow throughout the investigation are summarized in 8 steps.

Step 1. Equivalences between classifications.
Since the classification of sectors varies according to the country/region, the classification of Canada does not match the one in Europe. In order to be able to use the scenario data provided by the BoC, it is necessary to find equivalences between the classification used by the BoC, which is the North American Industry Classification System (NAICS), and the industry standard classification system used in the European Community (NACE). Even though not all the sectors have exactly an equivalent one, we match each of the sectors in our portfolio with the one with most resemblance (see Table B.1 in Appendix B). To do the matching, we are based on the list of equivalences between NAICS and NACE provided by Eurostat (website).

The use of standardized sector classifications is limited for our purpose since they usually do not take into consideration transition risk. So, the study and the data provided by the BoC is based on the 9 most emission-intensive sectors that are design for the analysis which are: livestock, forestry, crops, coal, refined oil products, oil & gas, electricity, energy-intensive industries and commercial transportation. It is assumed that the rest of the sectors are not emission intensive enough to be substantially impacted by climate risks. So we use the Appendix of the paper of BoC (Hossini, H. *et al.*, 2022 [26]) to classify our sectors into 9 most emission-intensive sectors mentioned above (see Table B.2 in Appendix B to see the classification).

Step 2. Disaggregate sectors into segments.
We have the borrower firms classified by sector. However, the exposure and the capacity to deal with transition risk may differ within a sector. While some companies may be harmed by a low-emission, other firms may benefit from it. For example, in the sector of transportation, transition could be very different for air transportation, water transportation, rail transportation or road transportation, or in the electricity sector, fossil fuel electricity could be very harmed while renewable electricity has a positive impact. That is why an additional layer of subsector or segment granularity could be interesting for risk analysis, so that we bring down sector-level risks to segment-level.

We are interested on segments that are homogeneous groups in which transition scenarios might impact in analogous ways. These are usually firms with a similar exposition to climate risk drivers.

There is not a standardized definition of segments for transition risk analysis. So, based on the segmentation of BoC, we adapt the segments according to the NACE classification code and the exposure of the portfolio to each sector and segment. Some segments are dismissed because no equivalent NACE codes are found. There are some segments to which the Entity is not very exposed. For example, the exposure to sectors such as coal, refined oil products or oil & gas is really low and they have few borrowers from those. In the case of Laboral Kutxa's portfolio, the Entity's main borrowers are SMEs located in Spain, especially in the Basque Country, which is an industrial area. So the sectors to which is most exposed to are energy-intensive industries and commercial transportation.

The final segmentation considered in the paper is shown in Table B.3 in Appendix B along with the NACE codes and the number of SMEs from our portfolio that belong to each of the segments.

Step 3. Construction of a heat map.
A heat map is useful to assess relative sensitivities of each segment defined in the previous step to the sectorial RFPs. The aim of Step 3 is to rank sensitivities into six levels: high, moderately high, moderate, moderately low, low or Negative. The heat map allows us to compare responses of different segments within the same sector, but it is not comparable across sectors.

Since the segmentation used in the analysis is equivalent to the one used by the BoC, we suppose that the sensitivities of the segments to the sectors RFPs would not vary significantly. So, we are based on the heat map design by the BoC to construct an equivalent one. In the design of the heat map the BoC compared different characteristics of the segments with the sector average in order to classify the sensitivities into different levels. For direct emission costs, they considered emissions-intensities; for indirect costs, input-output tables; for capital expenditures, marginal abatement cost curves; and for revenues, information to evaluate the impacts on revenues (e.g., price elasticity of demand for specific segments, information on a segment's market structure, and metrics from literature based on other scenario sources). The construction of the heat map is based on the Below 2°C immediate scenario which is considered to be the "average" view of the sensitivities and to be the same under the other scenarios.

Finally, the heat map construct in this paper can be seen in Table 2.1.

<table>
<tr><th>Sectors</th><th>Segments</th><th>Direct emissions cost</th><th>Indirect cost</th><th>Capital-expenditure</th><th>Revenues</th></tr>
<tr><td>1) Livestock</td><td>1) Livestock</td><td rowspan="5" colspan="4">Moderate</td></tr>
<tr><td>2) Forestry</td><td>2) Forestry</td></tr>
<tr><td>3) Crops</td><td>3) Crops</td></tr>
<tr><td>4) Coal</td><td>4) Coal</td></tr>
<tr><td>5) Refined oil products</td><td>5) Refined oil products</td></tr>
<tr><td rowspan="4">6) Oil & Gas</td><td>6) Extraction of crude petroleum and natural gas</td><td>Moderately high</td><td>Moderately low</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td>7) Support activities for petroleum and natural gas extraction</td><td>Moderately low</td><td>Moderate</td><td>Moderately low</td><td>Moderately high</td></tr>
<tr><td>8) Transport via pipeline</td><td>Moderate</td><td>Moderately high</td><td>Moderate</td><td>Moderately low</td></tr>
<tr><td>9) Distribution of gaseous fuels through mains</td><td>Low</td><td>Low</td><td>Moderately low</td><td>Moderately low</td></tr>
</table>

7) Electricity	10) Fossil-fuel electric power generation	Moderately high	Moderately high	Moderately high	Negative
	11) Hydro and nuclear electric power generation	Low	Low	Moderately low	Moderately low
	12) Other renewables electric power generation	Low	Moderately low	Moderately low	Moderately high
	13) Transmission, distribution and trade of electricity	Low	Low	Moderate	Moderate
8) Energy-intensive industries	14) Manufacture of paper and paper products, printing and related support activities	Moderately high	Moderately low	Moderate	Moderate
	15) Manufacture of chemicals and chemical products, manufacture of basic pharmaceutical products and pharmaceutical preparations, and manufacture of rubber and plastic products	Moderate	Moderately low	Moderately high	Moderate
	16) Manufacture of other non-metallic mineral products	Moderately high	Moderate	Moderately low	Moderate
	17) Manufacture of basic metals and manufacture of fabricated metal products, except machinery and equipment	Moderately low	High	High	Moderate
9) Commercial transportation	18) Air transportation	High	Moderately low	High	Low
	19) Rail transportation	Moderately low	Low	Moderately low	Moderately high
	20) Water transportation	Moderately high	Moderately low	Moderately high	Moderate
	21) Freight transport by road, transit and land passenger transportation, and other transportation (removal services, support activities for transportation, couriers and messengers, and warehousing and storage)	Moderately low	High	Moderate	Moderate

Table 2.1: Heat map tool with the sensitivities of the segments to the sectoral RFPs. (*Source: Hossini, H. et al., 2022 [26]*)

Step 4. Representative groups of each segment.
As we have explained earlier our aim is to translate transition scenario outputs into changes in the credit metrics of the borrowers. However, doing this translation directly for each firm could be costly and time consuming since they are impacted by several risk drivers. Those risk drivers can be quantitative, for example, emission costs or capital expenditures, and they can also be qualitative, for example, the firms' capacity to deal with a transition into a low-emission environment. Moreover, there is a lack

of information on firm-level risk drivers because the transition scenario outputs are estimated on a sector-level.

To overcome the lack of information, we analyze a representative group of firms for each of the segments and then, extrapolate the borrower-level impact to the rest of the portfolio. Analyzing each firm in the portfolio individually is very time and resource consuming. However, analyzing only a sample of borrowers and then extrapolating the results to the whole portfolio makes the portfolio impact assessment systematic and repeatable reducing the requirement of both time and resources. It is in the interest of the financial entities to minimize the number of cases that experts need to analyze individually.

The representative group used to calibrate the model in the next steps, contains 5 firms for each segment. The number of firms in the calibration group is related to the number of parameters that need to be estimated in the model [4] (see Equation 2.6). For the calibration group of each segment to be as representative as possible, it reflects not only the average of the segment, but also its dispersion. In order to accomplish that, the calibration group represents a wide range of values for different variables and characteristics such as credit ratings, size, province and nature of business operations.

Step 5. Borrower-level impact for the representative group.
Once we have a representative group for each segment, it is necessary to analyze the impact of the transition scenarios on the creditworthiness of the borrowers in the group. For that we need to use the Entity's quantitative credit tools and expert judgment to link the scenarios and the borrowers. This step requires great effort and time, since there is no much information about how to perform it. The historical data available is scarce and not very reliable. Moreover, the analyzed horizon is longer than in most of the risk assessment exercises and it is very important to understand how each segment could respond in different scenarios. So, many assumptions and expert opinions are needed. This causes a lack of consistency and comparability in the results.

On the basis of the variables provided by the BoC, we calculate the impacts of the transition scenarios on the borrowers' financial metrics that are usually indicative of credit risk, for example, variables that describe indebtness, activity, solvency, profitability and liquidity, among others. Taking into account the changes on those metrics, we use the credit rating model for SMEs of the Entity to obtain the scenario-adjusted PDs of the company.

Our main idea is to use linear regressions to predict the values of the financial metrics of the entity's credit model. It is difficult to find variables that can be used as input variables in the regression. We have borrower-level historical data of the representative firms' balance sheets, but sector-level future predictions data for each scenario in the

[4] In the shifted Merton model there are 5 parameters that need to be estimated. That is why we need at least 5 firms in the calibration group. In that case, the estimation will be unique.

Canadian dataset. We need to find variables that are available in both datasets or that can be used as proxies of each other. The most suitable variables we can use are Sales and Profit/Loss (Net income) for firms, and Production and Net income (Net income=Revenues-Direct emission costs-Indirect costs-Capital expenditure) for sectors. Even though Sales and Production are not financially the same, we used them as proxies of each other because they relate directly with borrowers' ability to pay debt. Higher values in them decreases the probability of the firm defaulting.

So, for each financial metric and sector we estimate by OLS the panel data linear regression on Equation 2.1. The historical data used in the estimation is not very extensive and we have very little information for some of the firms. The input variable used in the model is the ratio net income/sales of the sector. The financial metrics of the rating model are ratios with no unit, so the input variable introduced is also a relative variable without unit.

$\alpha_{i,G}$ and $\beta_{i,G}$ of the regression on Equation 2.1 collect the sensitivity of the borrowers' financial metrics to the sector-level input ratio. However, not all firms within a sector have the same characteristics or are impacted the same. To adjust and differentiate the sensitivities of each representative borrower to the sector in general, we introduce borrower dummies. In order to avoid perfect multicollinearity problems, we introduce a dummy for every borrower except for one that is incorporated in $\beta_{i,G}$, and the other parameters ($\beta_{i,j}$) are calculated with respect to that base borrower. We use panel data to estimate the regression, where we assumed that observations are independent of each other.

$$FinMetric_{i,j,t} = \alpha_{i,G} + \beta_{i,j}\frac{NetIncome_{G,t}}{Sales_{G,t}} * 1_j + \beta_{i,G}\frac{NetIncome_{G,t}}{Sales_{G,t}} + \epsilon_{i,j,t} \tag{2.1}$$

where $FinMetric_{i,j,t}$ is the financial metric i in the logit model in period t for the borrower j; $NetIncome_{G,t}$ and $Sales_{G,t}$ are the net income and sales of sector G in period t;; and 1_j is a borrower dummy that takes value 1 if the observation belongs to borrower j and 0 otherwise. The sectorial net income and sales are calculated as the sum of net incomes and sales of all the firms from Spain within the sector whose balance sheet information is available in ORBIS. So that we use an approximation of the total net incomes and sales of Spain for each sector.

Once we have estimated the parameters of the models, we can predict an estimation of the possible future values of financial metrics. We have no future information about the input of the model, but for each scenario considered, we do have estimations of net incomes and productions of each sector at aggregate level in Europe every 5 years between 2020 and 2050 under each scenario considered. So, we assume that the scenarios have a parallel impact on sectors in Europe and in Spain. We assume that in the baseline scenario, where no additional policy is implemented, the temporal variation for both geographies is the same. Thus, we calculate the variations of the net income and production for each sector in Europe and in the baseline scenario every 5 years relative to 2020. Based on our data of 2020, we apply those variations to the net income and sales of each sector in Spain as shown in Equation 2.2.

$$\frac{NetIncome_{G,BASE,t}}{Sales_{G,BASE,t}} = \frac{\frac{NetIncome_{G,BASE,EU,t} - NetIncome_{G,BASE,EU,2020}}{NetIncome_{G,BASE,EU,2020}} NetIncome_{G,2020}}{\frac{Production_{G,BASE,EU,t} - Production_{G,BASE,EU,2020}}{Production_{G,BASE,EU,2020}} Sales_{G,2020}} \tag{2.2}$$

where $NetIncome_{G,BASE,EU,t}$ and $Production_{G,BASE,EU,t}$ is data provided by the BoC for Europe under the baseline scenario for $t = 2025, 2030, 2035, 2040, 2045, 2050$.

In order to predict the ratio for the adverse scenarios, we assume that the variation of each scenario relative to the baseline are also parallel for Europe and Spain. So, for each of the 3 adverse scenarios (Below 2°C Delayed, Below 2°C Immediate and Net-Zero 2050) we calculate the variations of the net income and production for each sector in Europe every 5 years relative to the baseline scenario. Based on the predictions calculated in Equation 2.2, we apply the same variation as shown in Equation 2.3.

$$\frac{NetIncome_{G,SCEN,t}}{Sales_{G,SCEN,t}} = \frac{\frac{NetIncome_{G,SCEN,EU,t} - NetIncome_{G,BASE,EU,t}}{NetIncome_{G,BASE,EU,t}} NetIncome_{G,BASE,t}}{\frac{Production_{G,SCEN,EU,t} - Production_{G,BASE,EU,t}}{Production_{G,BASE,EU,t}} Sales_{G,BASE,t}} \tag{2.3}$$

for $t = 2025, 2030, 2035, 2040, 2045, 2050$ and SCEN=BELOW 2°C DELAYED, BELOW 2°C INMEDIATE, NET-ZERO 2050. Therefore, we get an estimation of the input of the model for each sector from 2025 to 2050 every 5 years under each one of the 3 adverse scenarios analyzed.

Introducing the input estimations in the estimated models in Equation 2.1, we obtain predictions of the financial metrics for each representative firm under each scenario and period. Once we have predictions of possible impacts on the financial metrics under each scenario, we introduce them in the logit credit risk model. That way, we get the predictions of the scenario-adjusted PDs for each representative firm and period under different scenarios. These scenario-adjusted PDs are used as calibration points in the next steps of the methodology.

Step 6. Calibrate the shifted Merton model.
In order to capture the impact of different transition scenarios and extrapolate the changes in the creditworthiness of a sample of borrowers to the overall portfolio, we use a Merton styled model. This combines bottom-up calibration points and top-down scenario parameters with an approach that is systematic and repeatable. The Merton model is a well-known credit model that is mainly used to estimate PDs (see Goswin, T. [25]). The model was first developed by Robert Merton in 1974. Merton was based in the idea that an event of default depends on the relation between a firm's assets and liabilities. The event of default occurs when the value of the assets on the company's balance sheet falls below a certain threshold. That threshold is considered to be the value of liabilities of the firm.

We consider a simplified structure of a firm's balance sheet. So, the total value of assets, V_t, is equal to the sum of the value of the equity, E_t, and the value of liabilities or debt, D_t: $V_t = E_t + D_t$. Since debt has payment preference, the shareholders receive the residual value that remains after debt owners are paid. If assets fully cover debt, the value of equity is positive and there is no default. However, if debt is not fully covered, $V_t < D_t$, it is considered that the company is in default and the value of equity is 0. So, the total value of equity can be expressed as $E_T = max(0, V_T - D_T)$ being T the moment of a possible event of default.

Merton proposed to model the firm's equity as a call option on the company's assets with its debt as the strike price. So that it uses the Black-Scholes-Merton option pricing method to find a relationship between the balance sheet of the firm and their default risk. In that case, $PD = P(V_T < D_T)$ is the same as the probability of not exercising the call option (see Figure 2.2).

Black-Scholes-Merton (1973) assumes that the underlying follows a geometric Brownian motion. So, we assume that the firms' assets follow a lognormal distribution. According to Black-Scholes-Merton option pricing method, the observable market value of the equity relates with the unobservable market value of the assets for any moment prior to T as shown in Equation 2.4.

$$E_t = V_t N(d_1) - D_t e^{-r(T-t)} N(d2) \tag{2.4}$$

and

$$d_1 = \frac{ln(\frac{A_t}{D_t} + (r + \frac{1}{2}\sigma^2)(T-t)}{\sigma\sqrt{T-t}}$$

$$d_2 = d_1 - \sigma\sqrt{T-t}$$

where σ is the volatility of the value of the assets and r is the logarithmic risk-free rate of return.

Moreover, Black-Scholes-Merton indicates that the probability of exercising the option is equal to $\Phi(d_2)$. So, the probability of not exercising the call option, or in our case the probability of default, is shown in Equation 2.5

$$PD = 1 - \Phi(d_2) = \Phi(-d_2) \tag{2.5}$$

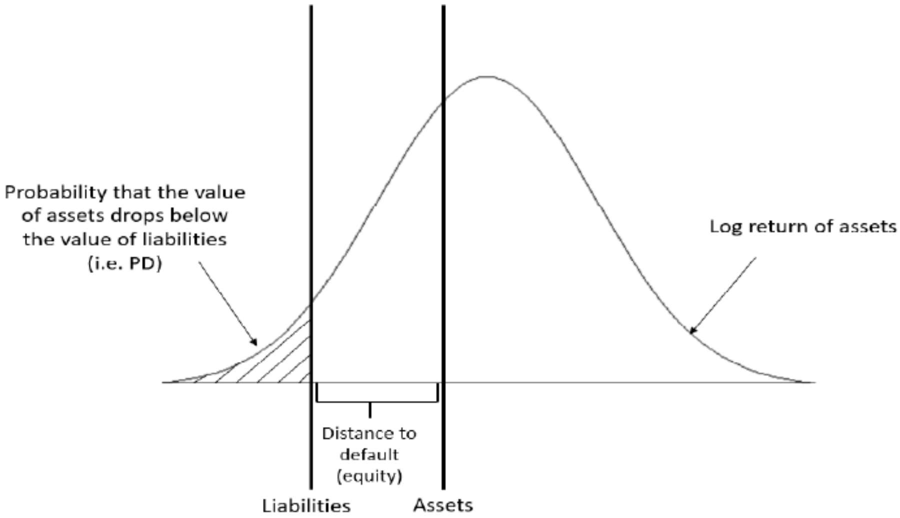

Figure 2.2: Representation of the PD under the Merton model. (*Source: Hossini, H. et al. (2022) [26]*)

So, changes in the PDs are caused by a continuous and normally distributed credit indicator (d_2). This indicator can be divided into two components: systemic component and idiosyncratic component. Climate transition risk drivers are not firm specific risks since as explained in the Introduction, climate risk is systemic and affects the entire financial stability. So, the RFPs provided by the BoC that capture transition risk drivers are an additional systemic risk that shifts the model keeping idiosyncratic and other systemic factors unchanged. That shift is known as "climate credit quality index" and is the sum of the products of the RFPs and the sensitivities of the segments to those RFPs multiplied by a scaling factor. This could lead to both increases and decreases in PDs. So, the conditional PD of transition scenarios can be calculated using the shifted Merton model applying the Equation 2.6.

$$PD_{ijk|c^*} = \Phi[\Phi^{-1}(PD_{ijk,TTC}) - \frac{1}{\alpha_k}\sum_r s^r_{j,k} f^r_k] \tag{2.6}$$

where $PD_{ijk|c^*}$ is the scenario-adjusted PD for the borrower i in segment j and sector k, $PD_{ijk,TTC}$ is the initial through-the-circle PD of borrower i, Φ is the standard normal distribution, f^r_k is the risk factor r for the sector k [5], $s^r_{j,k}$ is the sensitivity of segment j in sector k with respect to the risk factor r and α_k is the scaling factor to normalize the RFPs. We need to estimate α_k and $s^r_{j,k}$. We use the initial Through The Circle PD of the borrowers as a basis because it is stationary and does not depend on the economic cycle, that is, does not grow in periods of expansion and does not fall in periods of contraction. We estimate the PD_{TTC} as the average historical PD of each firm.

[5]Note that an increase in costs should be inserted with the opposite sign that an increase in revenues as the sum would represent the profit of the sector.

The estimation of the parameters is carried out in two stages. First, all the sensitivities are set to one and we estimate α_k for each sector using least squares optimization based on the calibration points. For that, we estimate the regression in Equation 2.7 by OLS.

$$[\Phi^{-1}(PD_{ijk,TTC}) - \Phi^{-1}(PD_{ijk|c^*})] = \frac{1}{\alpha_k} \sum_r s^r_{j,k} f^r_k + \epsilon_{ijk|c^*} \tag{2.7}$$

Once we know the estimated value of α_k for each sector, we need to estimate four sensitivities for each segment, one for every RFP. In the same way as in the previous calibration, we estimate using least squares optimization based on the calibration points obtain in step 5. To prevent sensitivities from taking extreme values, we define upper and lower bounds for each level. Not to totally rely on the quantitative results and take into account the qualitative aspects and experts' opinions, it is important for the estimated sensitivities to be consistent with the heap map designed on step 3. So, in the estimation of the sensitivities we set constraints that assure that Low sensitivity is lower than Moderately Low, which at the same time is lower that Moderate, and so on. As $s^r_{j,k}$ measure the sensitivity of the segment j in sector k with respect to the risk factor r, the order mentioned is followed within a sector, but is independent across sectors.

Step 7. Extrapolate the changes in the PDs to the rest of the portfolio.
Once we have calibrated all the parameters of the model based on the representative group, we extrapolate the results to any portfolio. Using the estimated shifted Merton model we can project the scenario-adjusted PD based on the initial credit rating and segment of any hypothetical borrower. So, for each company on the loan portfolio, we consider the values of the parameters corresponding to its sector and segment, and the PD_{TTC} estimated by the entity's internal logit model. Thus, we project the conditional PD under each of the analyzed scenarios applying the estimated Equation 2.6.

Step 8. Project the changes in the LGDs (Frye-Jacobs).
It is also interesting to analyze the impact of transition risks in other credit metrics, such as LGD. Usually borrowers' LGD is not easily estimated due to data scarcity. Moreover, LGDs are commonly calculated as a constant parameter or as an independent variable of the PD. However, empirical evidence has shown that these two metrics are not independent (see Altman, E. I., *et al.*, 2005 [3]). More frequent defaults are usually followed by devaluation of assets and lower Recovery Rates. Not considering the relation between LGD and PD may lead to underestimating credit risks (see Santos, A., 2020 [37]).

One way of relating the metrics could be using correlation between PD and LGD but that would require calibrating new parameters. Frye and Jacobs (2012) predicts LGD as a positive function of the default rate without needing to calibrate new parameters (see Frye, J., 2013 [23]). The Frye-Jacobs LGD function allows to avoid unnecessary parameters and noise in the predictions by using only parameters that are already part of the credit model of PDs. Frye demonstrated that the model is suitable for stress testing exercises because it performs well under different scenarios.

We use the Frye-Jacobs LGD model (Equation 2.8) to estimate the scenario-adjusted LGD based on scenario-adjusted PDs calculated in the previous step and the entity's initial estimation of the borrowers' PDs and LGDs for each year under different scenarios.

$$LGD_{ijk|c^*} = \frac{\Phi[\Phi^{-1}(PD_{ijk|c^*}) - [\Phi^{-1}(PD_{ijk,TTC}) - \Phi^{-1}(PD_{ijk,TTC} * LGD_{k,TTC})]]}{PD_{ijk|c^*}} \tag{2.8}$$

Chapter 3

Empirical exercise

3.1 Data.

The portfolio analyzed in the exercise is a random sample that contains SMEs in the Spanish market. A part of the loan portfolio of Laboral Kutxa is included in the sample. To complete the lack of firms in some of the sectors and variables, we also download some data from ORBIS. The data has been transferred for the purpose of the analysis of the paper and the conclusions are not representative of the credit situation of the Entity.

Laboral Kutxa is a Basque financial institution whose purpose is to satisfy the financial needs of its members and clients, preferably individuals and companies. It is one of the most relevant financial institutions in the Basque Country and the biggest one under direct supervision of the Bank of Spain.

Even though Laboral Kutxa is not required by the BCE to carry out a climate stress test, the Entity believes that it is important to little by little analyze and incorporate climate risks in its risk management since it is a subject that is becoming very relevant and could have a significant impact in the future.

In order to analyze our portfolio of SMEs, we aggregate them in homogeneous groups so that the problem of lack of data is overcome. To create the groups we are based on the NACE code, classifying the firms by sector and segments. Given the lack of historical data, banks develop their own estimates for some of the characteristics of the firms that could differ significantly from each other. These difficulties make working with SMEs costly and time consuming.

The fact that large firms can be individually analyzed, allows us to compare their climate-related metrics and vulnerabilities across sectors, sizes or countries, among others. However, the comparison is more difficult for SMEs due to lack of data and resources. That is why those metrics are calculated for an aggrupation of them and we usually lack individual data. Even though we have classified them into homogeneous groups in terms of transition risks, there may be some firm specific information we are not considering and that could be relevant, for example, their capability to deal with those transition risks. This shows the importance of using data as much granular as possible for assessing climate risks.

The data used in the analysis contains information on 3.391 SMEs and their ratings since October 2016. The dataset also contains many variables related to the borrowers' balance sheet, such as total assets, sales, profit and loss, debts, etc. from 31DEC2014 to 31DEC2020. Additional information like NACE code, province, size, etc. was also available. To know a little bit better the sectors considered in the analysis, Table 3.1 contains the average value of some variables of the balance sheet for each sector in 2020.

Sector	Total Assets	Sales	Profit & Loss	Debt	Liquidity Ratio
Livestock	8.230.287,53	8.975.543,45	447.534,165	3.468.771,66	3,0291
Forestry	2.720.012,4	2.989.605,8	107.465,95	973.350,56	2,7163
Crops	7.423.662,05	2.844.229,79	107.149,5	1.989.017,16	4,3008
Coal	7.603.383,6	3.341.105,8	385.767,4	790.529	4,2021
Refined Oil Products	729.544.848	1.194.980.618,33	-46.402.685	70.557.818,67	1,4452
Oil & Gas	616.604.824	85.923.959,15	5.645.537,65	325.838.336,71	5,1876
Electricity	106.584.840	30.579.682,74	6.871.093,12	56.705.365,56	2,8485
Energy-Intensive Industries	17.236.108,4	15.339.185,55	751.565,95	5.360.738,49	3,1816
Commercial Transportation	12.765.428,2	7.874.356,7	14.411.69	5.914.926,65	2,6492

Table 3.1: Sectoral average values of some variables from the balance sheets.

Some sectors contain very little firms so the average values of some variables may be biased by extreme values for some firms, especially in sectors coal, refined oil products and oil & gas.

The information provided is enough to calculate the financial ratios used in the internal credit model that estimates the PDs of the debtor, which is a logit model.

Since in the internal estimations of LGD of the entity for SMEs the variable sector is not considered, we apply the mean discounted ultimate Recovery Rates 1988-2011 provided by Altman and Kalotay (2014) for each group of industry. The industry groups provided in the article and the sectors we want to analyze using NACE codes are not exactly equivalent. So, we match each sector to the most similar industry group and if more than one industry groups belong to the sector, we calculate the mean of their LGDs. The matching between sectors and the average Recovery Rate and Loss Given Default can be seen in Table 3.2.

Sector	Industry Group	Discounted Ultimate Recoveries (Mean)	Loss Given Default
Livestock	Food	0.6265	0.3735
	Other		
Forestry	Other	0.561	0.439
Crops	Food	0.6265	0.3735
	Other		
Coal	Mining	0.623	0.377
Refined Oil Products	Oil	0.6215	0.3785
	Chemicals		
Oil & Gas	Oil	0.7045	0.2955
	Utilities		
Electricity	Utilities	0.864	0.136
Energy-intensive industries	Chemicals	0.6272	0.3728
	Drugs, soap, perfume, tobacco		
	Construction and materials		
	Steel		
	Fabricated Products		
Commercial transportation	Transport	0.517	0.483

Table 3.2: Loss Given Default of each sector. (*Source: Altman, E. I. and Kalotay, E.A., 2014 [4]*)

3.2 Empirical results.

Applying the methodology explained in Section 2.3, we obtain 3.391 individual PDs and LGDs for each period and scenario analyzed. Afterwards, we estimate the ECL of different portfolios for those periods and scenarios. This section presents the results obtained.

3.2.1 Probability of Defaults.

In this paper, we focus on analyzing possible shocks in PD due to transition risks. So, we assume that these shocks do not impact on the Baseline scenario and the PD remains constant at its historical average level (PD_{TTC}). However, sectors show different reactions under adverse scenarios. Figure 3.1 represents the median PD of each sector for each period and scenario.

We can see that for most of the sectors, transition scenarios increase the PDs notably, being crops, refined oil products and oil & gas the sectors that show the highest PDs by 2050. Instead, livestock, electricity and commercial transportation show a decrease in their PDs in the long-term under almost every scenario. Initially, in some scenarios, these sectors show an increase in the PDs that could be caused by rising costs and capital expenditure needed to purchase new technologies. However, in the long-term, those innovations allow them to satisfy customer preferences and increase their revenues, that way improving their credit quality. The exception is livestock for the Net-Zero 2050 scenario.

The representation of the PDs of the coal sector can draw attention. We expected the sector to show a greater impact. However, analyzing the scenario data used, we can see that it shows a significant decrease in revenues relative to the Baseline under scenarios Below 2°C Immediate and Net-Zero 2050 when the period of time refers to 2020-2025. However, for these scenarios and for the future time band, we do not observe significant changes in the RFPs. In the case of the Below 2°C Delayed scenario, we can see that for every RFP and period, changes relative to the Baseline are very small.

Looking at the general behaviour of all the sectors, in the Below 2°C Delayed scenario, where no further policies are implemented until 2030, the PDs remain constant until then. For the next years and for most of the sectors the scenario shows a sharper impact. On the contrary, the scenario with the smoothest variations is Below 2°C Immediate scenario, in which policies are immediately and progressively implemented. This scenario impacts more smoothly in the borrowers credit quality since measures are being taken immediately, which allows policies to be less restrictive and firms can slowly adapt to them. Below 2°C Immediate and Net-zero 2050 both impact immediately. Even so, Net-Zero 2050 scenario is more ambitious in the long-term and we can say that it hits harder that the Below 2°C Immediate scenario.

After focusing on the median evolution of the PDs by sectors and scenarios, we compare the PDs to the Baseline scenario, analyzing also the dispersion within the sector. We consider the change in the PDs relative to the Bseline scenario, where the PD remains constant. The change in PD relative to PD_{TTC} makes it easier to compare across sector. Figure 3.2, 3.3 and 3.4 allow us to see the evolution of the variations of the PDs over the horizon, as well as comparing the evolution across sectors and scenarios. In the figures we can see the evolution of the change in the PDs relative to the Baseline in basic points. The line shows the median change, the darkest area represents the interquartile range and the lightest area the variations between the percentile 5 and 95.

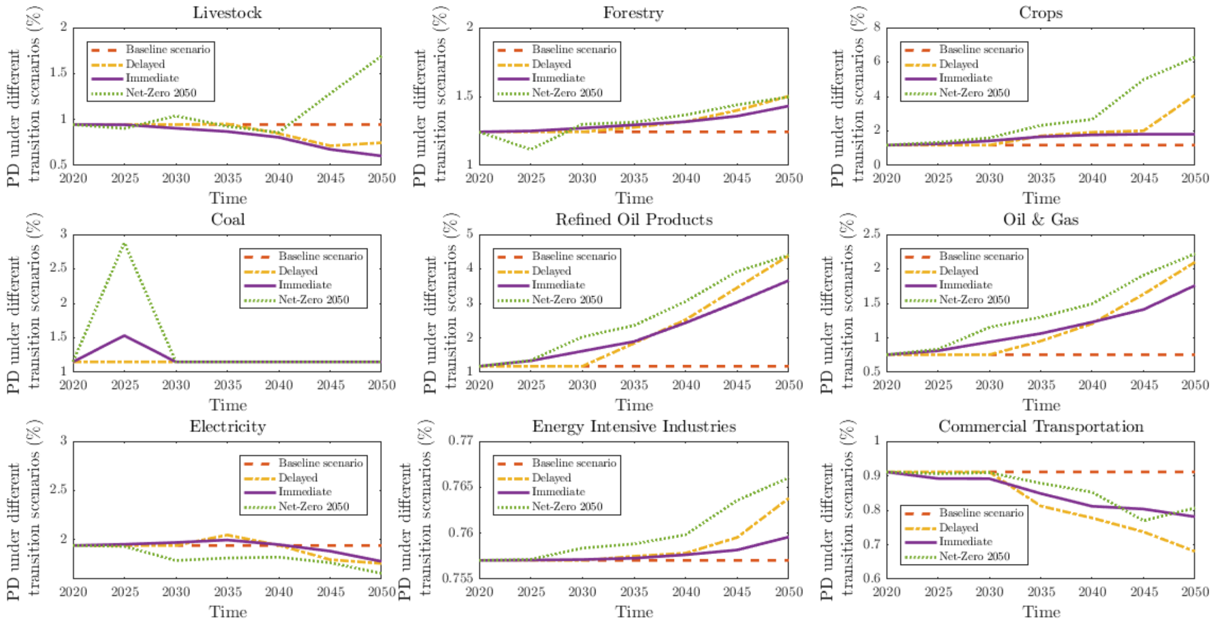

Figure 3.1: Median conditional PD of every sector for different scenarios over time.

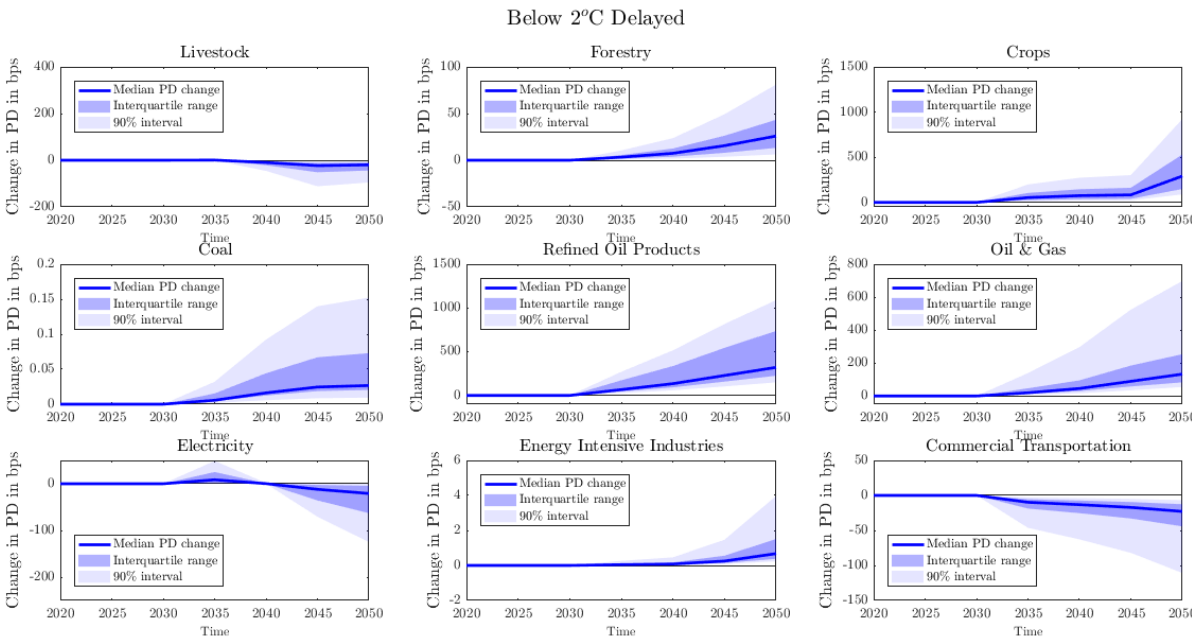

Figure 3.2: Median, interquartile range and 90% interval of the change in the PD relative to the baseline under Below 2°C Delayed scenario.

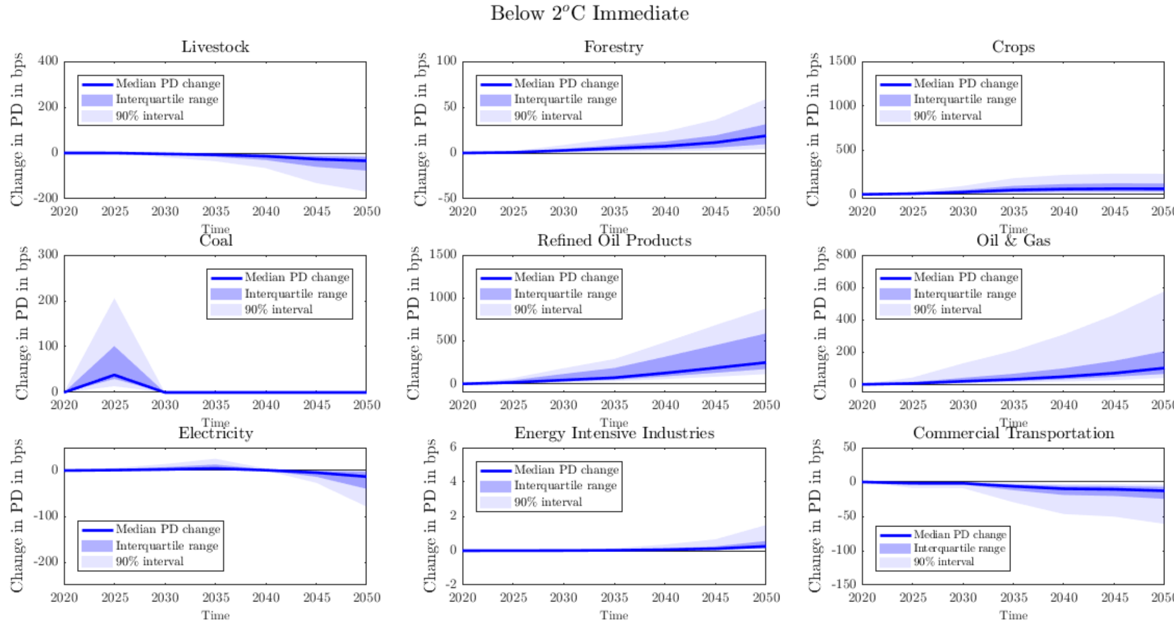

Figure 3.3: Median, interquartile range and 90% interval of the change in the PD relative to the baseline under Below 2°C Immediate scenario.

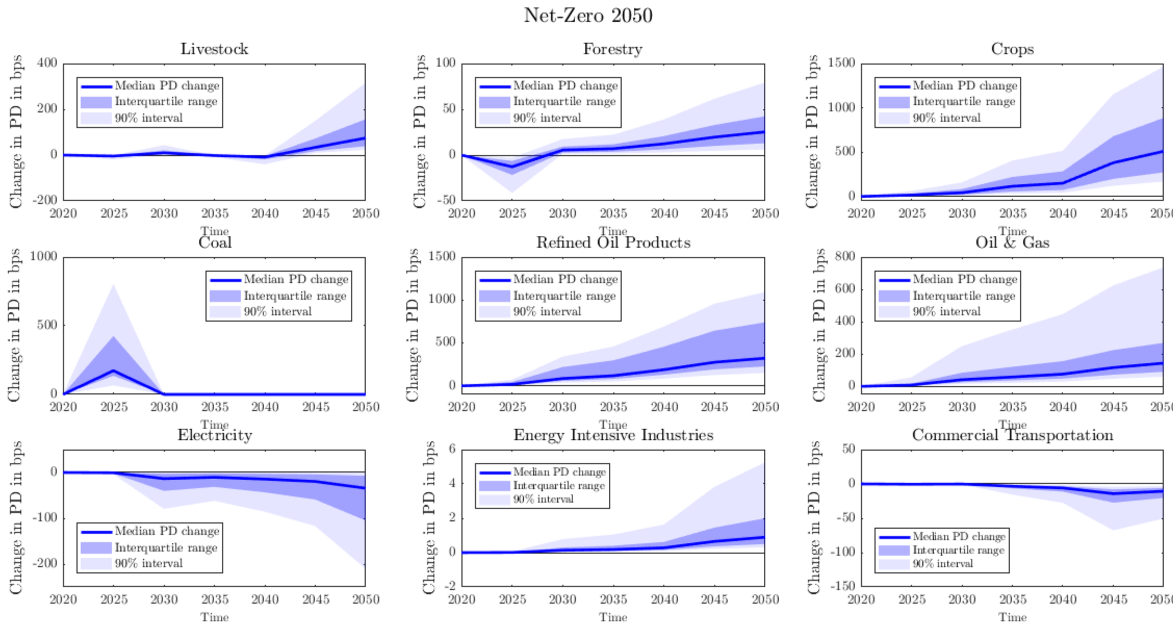

Figure 3.4: Median, interquartile range and 90% interval of the change in the PD relative to the baseline under Net-Zero 2050 scenario.

Similarly to Figure 3.1, we can see that the sectors that show the biggest variations relative to the Baseline are crops, refined oil products and oil & gas, while the most resilient ones are livestock, electricity and commercial transportation. Figure 3.2, 3.3 and 3.4 also represent the dispersion of the variation of each sector relative to the median. In general, the scenario where the variations are more concentrated around the median change is the Below 2°C Immediate scenario. In other words, under the Below 2°C Immediate scenario, the creditworthiness of the firms within the same sector changes similarly and in a less pronounced way . Instead, in the Below 2°C Delayed and Net-Zero 2050 scenarios, changes in PDs show more dispersion. So, under those scenarios there are more differences in the impacts on the credit profile of the firms within a sector. Some firms show a bigger impact, while others show smaller impacts.

We have analyzed impacts on PD and differences across sector, but it is also interesting to analyze differences across segments within a sector, especially for the electricity and commercial transportation sectors. Each of these sectors is divided into 4 segments and we can expect for firms to be impacted differently according to the segment they belong to. While some are very negatively impacted, others may be less impacted or positively impacted. To summarize the results, we have selected 3 different time points: short-term, medium-term and long-term. We consider a 10-year gap between each of the horizon. Thus, we consider short-term 2030, medium-term 2040 and long-term 2050. For each time point we consider the median change relative to the baseline for each group we are interested in comparing.

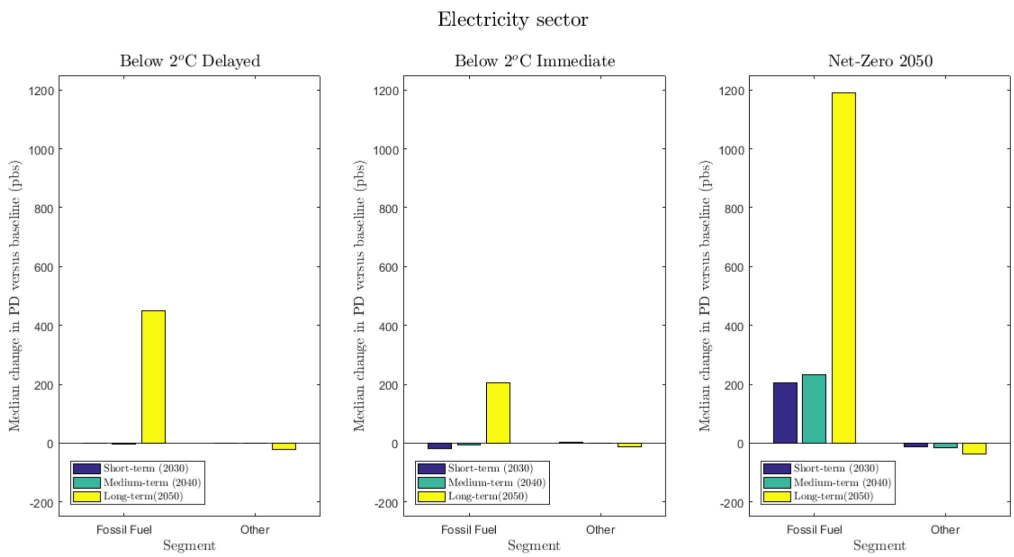

Figure 3.5: Median change in PD relative to the baseline in the short-, medium- and long-term for different segments within the electricity sector.

For the electricity sector, scenarios affect very differently to the segments. As we can see in Figure 3.5, firms in the segment of fossil-fuel electric power generation show more damage that the rest of the segments. Electricity generated by fossil-fuels have a lot of direct emissions, so transition policy would make their emission costs to increase and customers would change their preferences towards more sustainable alternatives, decreasing the segment's revenues. In the long-term, the scenario with most impact on this segment is the Net-Zero 2050 scenario, where sharper policies are implemented. On the contrary, the Below 2°C Immediate scenario is the one with the least impact on the PDs.

The rest of the segments in the electricity sector are greener alternatives that include Hydro, nuclear and other renewables power generations. Even though in the short-term these segments can be impacted negatively, in the long term they show a decrease in the PDs thanks to the reduction of emission cost and the increase of revenues. In a similar way, the best results for these segment are shown under the Net-Zero 2050 scenario.

In the same way, commercial transportation sector show differences across segments (see Figure 3.6). Air transportation is the most polluting mean of transport. So, a transition toward a lower emission environment would be especially harmful for this segment in comparison with other means of transport. The Net-Zero 2050, which is the most restrictive scenario, is the most harmful scenario for the air transportation segment. Rail, water and road transportations are less emissive or are currently developing alternatives that are more sustainable. Thus, in the long-term emission costs would decrease and revenues would increase, improving their creditworthiness. The three scenarios impact similarly on these group of segments and the Below 2°C Delayed shows a slightly better credit profile.

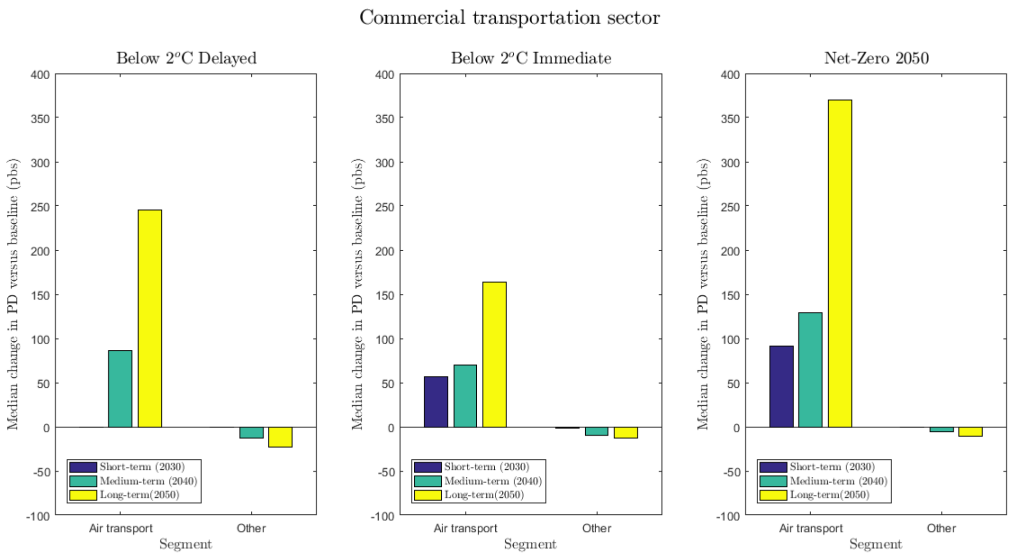

Figure 3.6: Median change in PD relative to the baseline in the short-, medium- and long-term for different segments within the commercial transportation sector.

3.2.2 Loss Given Defaults.

Once we calculate the conditional PDs, we can estimate the conditional LGDs applying the Frye-Jacobs relationship in Equation 2.8 (see Frye, J., 2013 [23]). That way, we obtain individual LGDs for each of the 3.391 firms.

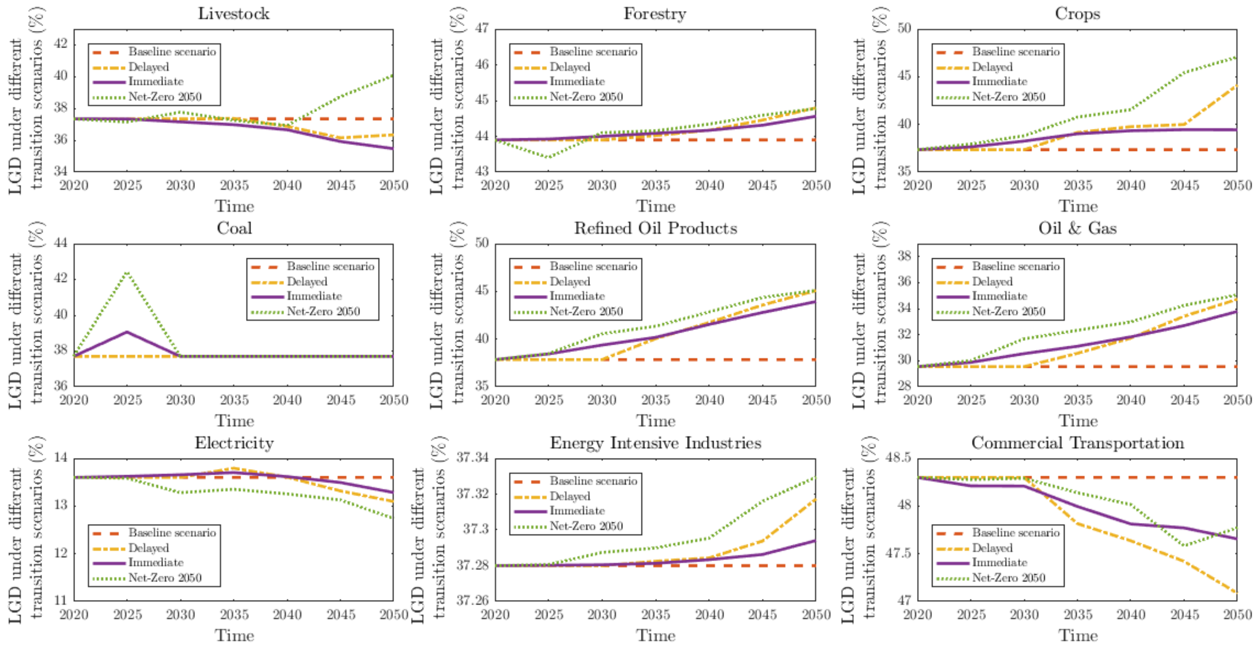

Figure 3.7: Median conditional LGD of every sector for different scenarios over time.

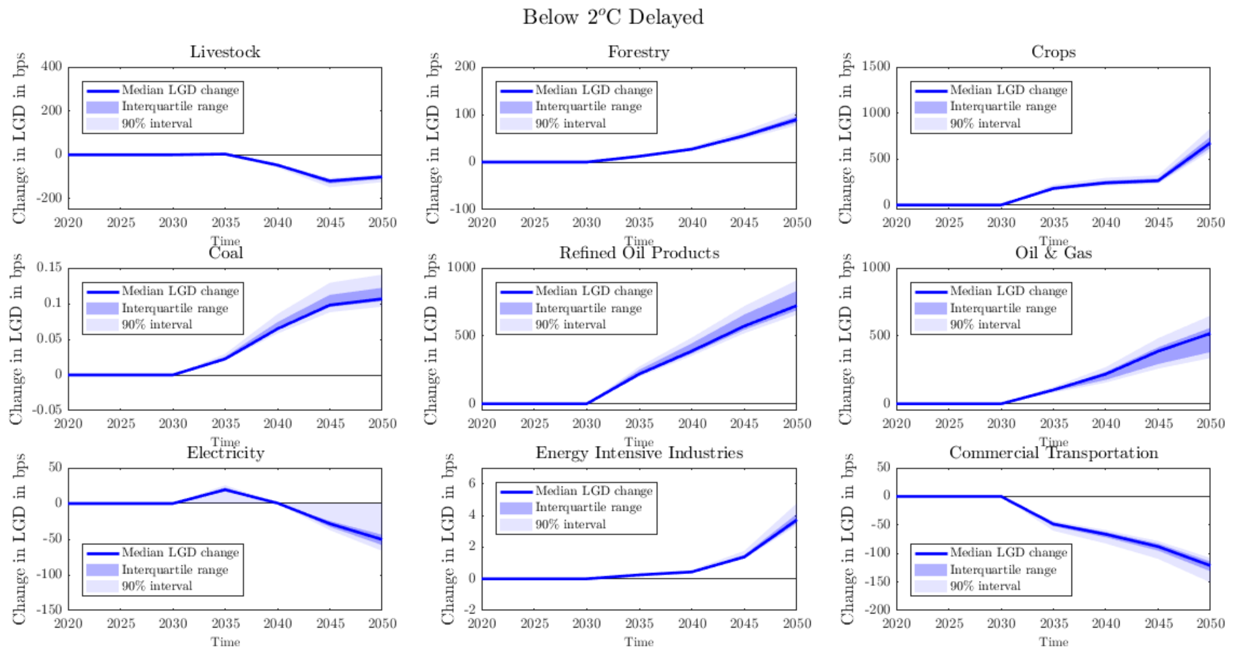

Figure 3.8: Median, interquartile range and 90% interval of the change in the LGD relative to the baseline under Below 2°C Delayed scenario.

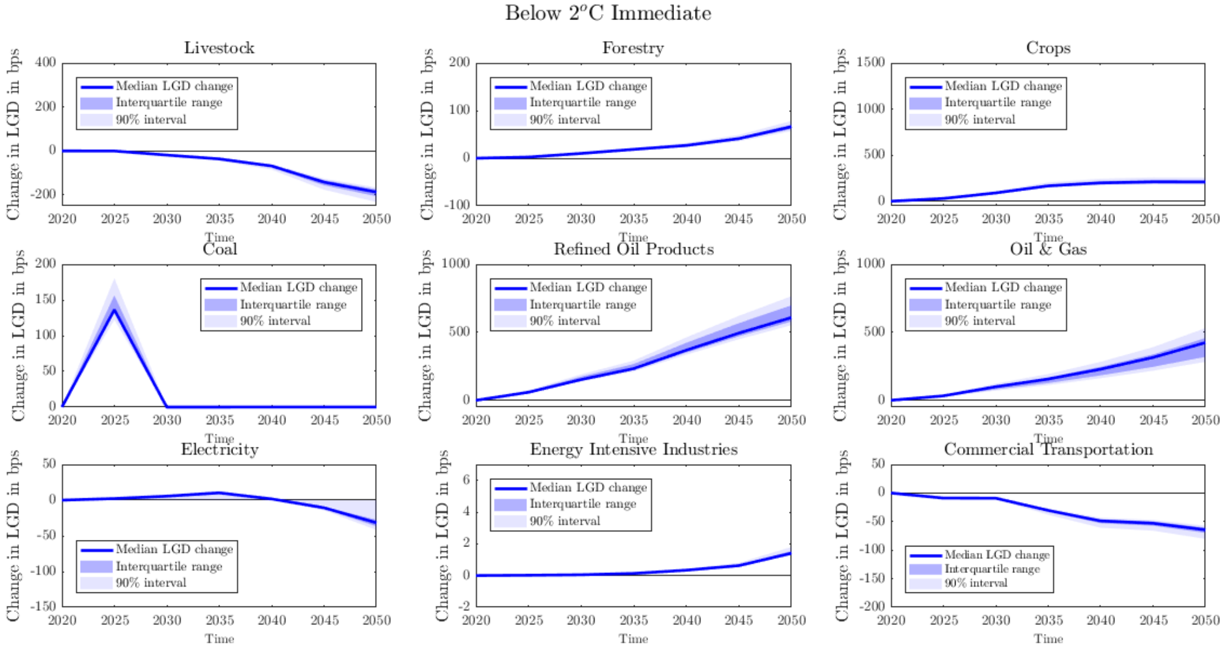

Figure 3.9: Median, interquartile range and 90% interval of the change in the LGD relative to the baseline under Below 2°C Immediate scenario.

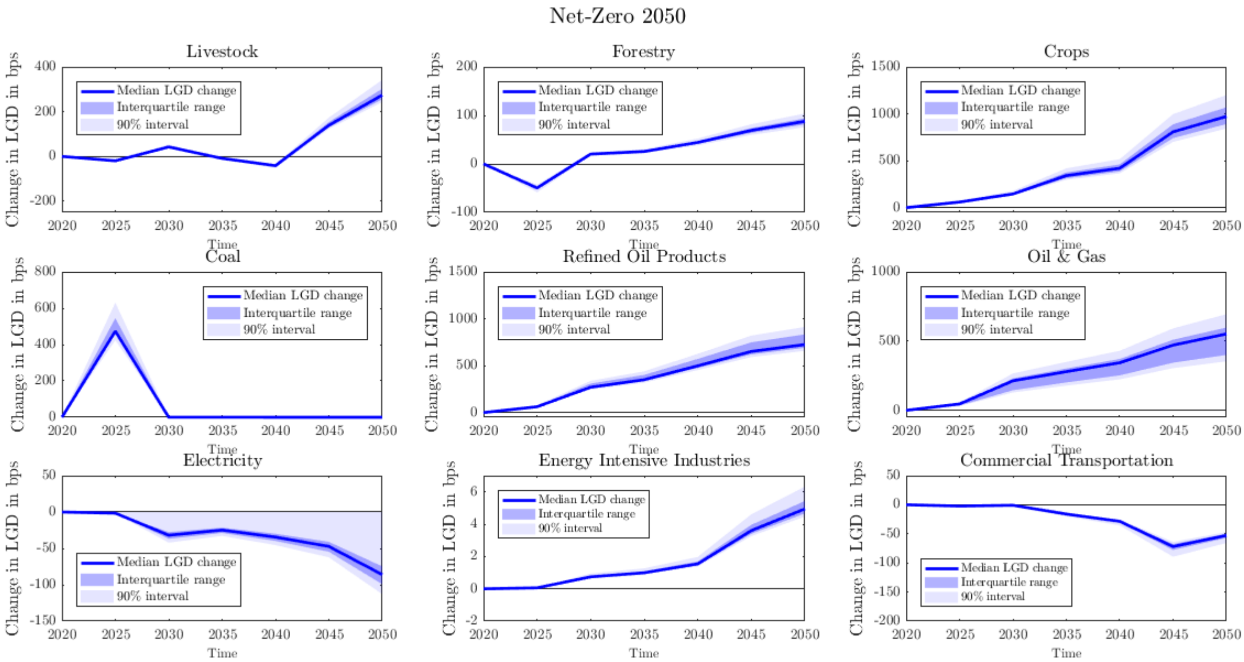

Figure 3.10: Median, interquartile range and 90% interval of the change in the LGD relative to the baseline under Net-Zero 2050 scenario.

In a similar way to PDs, we represent the median LGD of the firms of each sector for every period and scenario (see Figure 3.7). Once more, for the baseline scenario the LGD remains constant as the LGD_{TTC} that is assign depending on the sector it belongs to. We can see that initially, the sector with the highest LGD is commercial transportation. However, by 2050 the sector shows a decrease in the LGD, while others, such as forestry, crops or refined oil products, show an increase, reaching similar levels of LGD.

We have also represented the median, the interquartile range and the 90% interval of the change in LGD relative to the baseline for every sector, period and scenario (see Figure 3.8, 3.9 and 3.10). The tendencies of the changes in LGD are similar to the ones seen in the changes in PD. However, LGD shows less dispersion than PDs. One of the sectors with most dispersion is electricity, which especially in the Net-Zero 2050 and in the Below 2°C Delayed scenarios shows great differences on the impact on different firms. Similarly to PDs, the sector that show the biggest changes relative to the baseline are crops, refined oil Products and oil & gas, and in general, Net-Zero 2050, and in some cases Below 2°C Delayed, show the strongest impact.

3.2.3 Expected Credit Loss.

Once we have estimated the conditional PDs and LGDs, we can estimate the Expected Credit Loss for different possible portfolios. We created 10.000 random different equally-weighted portfolios of 100 firms whose composition tries to replicate part of the exposure by sector of the Spanish economy following the sector allocation published in the statistical bulletin of the Banco de España for the fourth trimester of 2021 [10]. We round and normalize the percentages of the sector composition to match our classification and for them to sum 100%. Finally, we classify the sector into 4 groups. The classification and the composition of the portfolios created can be seen in Table 3.3. Moreover, we assume that the exposure of each portfolio is 1 million EUR.

We calculate the ECL using the Equation 3.1, similarly to the definition seen in Equation 1.1.

$$ECL_{c^*} = \sum_i PD_{i|c^*} * LGD_{i|c^*} * EAD_i \tag{3.1}$$

Industry Groups	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**TOTAL**
Sectors	Livestock, Crops and Forest	Energy-Intensive Industries, Refined Oil Products, Coal and Oil & Gas	Electricity	Commercial Transportation	
BdE percentage	4.1%	19%	18.6%	6.8%	48.5%
Normalized percentage	8.45%	39.18%	38.35%	14.02%	100%
Rounded normalized percentage	9%	39%	38%	14%	100%
Number of firms	9	39	38	14	100

Table 3.3: (*Source: Statistical bulletin of the Banco de España for the fourth trimester of 2021 [10]*)

Figure 3.11 show the median ECL and the 95% interval along the horizon. The initial ECL remains constant in the baseline scenario. For the rest of the scenarios, the ECLs vary along the horizon. In the Below 2°C Immediate scenario, the ECL does not show a big impact. It gradually increases a little, but in the long-term it starts to recover. Instead, in the Below 2°C Delayed scenario, ECL remains constant until 2030, where new policies are implemented. Between 2030 and 2040, ECLs suffer a slight increase that become sharper between 2045 and 2050. Finally, the Net-Zero 2050 scenario shows the biggest increase. Under this scenario, ECL starts to increase immediatly in a progressed way. From 2040, the increase becomes more pronounce reaching up to approximately 0.15% more ECL.

It can be interesting to know what sector causes the variation on the portfolios ECLs. In order to analyze these effects we represent in Figure 3.12 the average ECL that each group contributes to the total average.

We can see that in the baseline scenario the average ECL remains constant at approximately 0.65%. The other 3 scenarios show variations through the years. The group with the biggest average contribution is the Group 2, which has the biggest weight and includes some of the sectors most harmed by the transition scenarios. The group that shows the biggest change in the average contribution is Group 1, which increases gradually over time. On the contrary, the contribution of the Group 4 and Group 3 remains almost constant even thougth they slightly reduce. Those groups include the most resilient sectors whose PD and LGD decrease over time under transition scenarios. However, they include some sector that are significantly harmed and that kind of compensate the reduction on the ECL of the other segments.

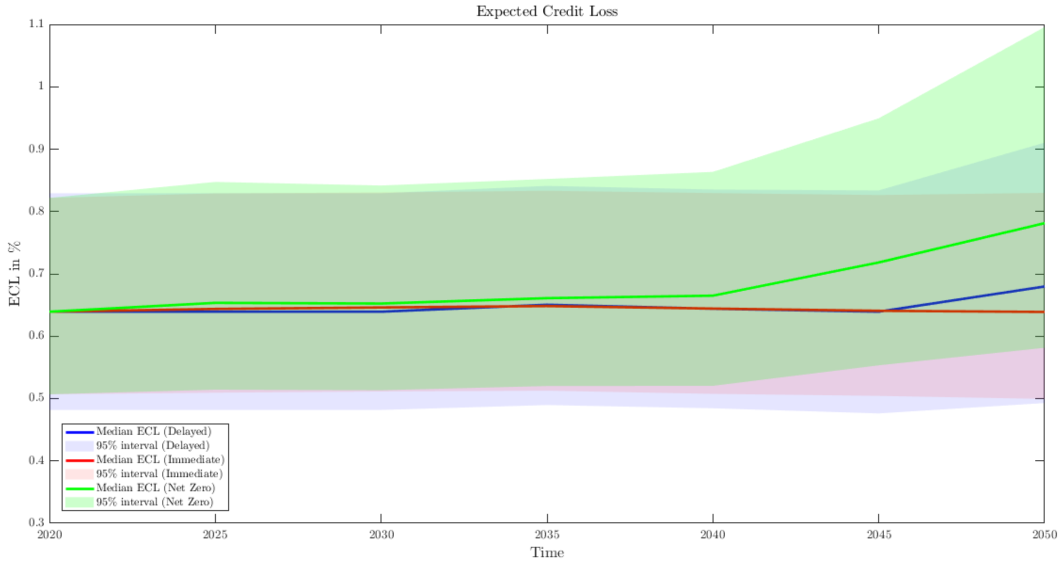

Figure 3.11: Median ECL and 95% inteval of the 10.000 portfolios under different scenarios over time.

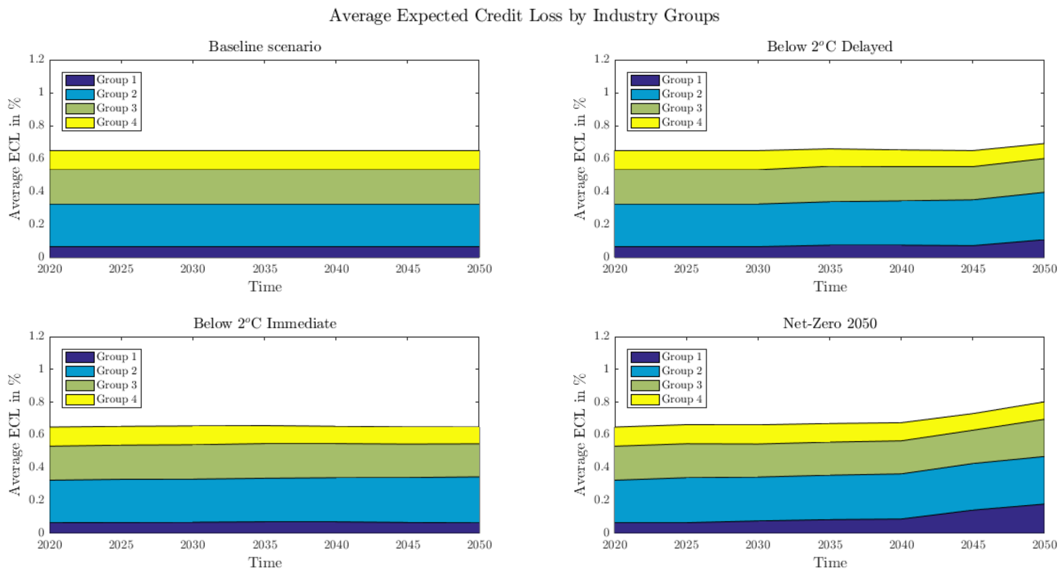

Figure 3.12: Average contribution of each industrial group to the average ECL of the portfolios.

Finally, we can try to analyze the distribution of the ECL for different periods and scenarios. For that, we represent the Kernel function corresponding to the histogram of the ECL in the short-term, medium-term and long-term under different scenarios (see Figure 3.13). The Kernel function show heavy tails, especially in the long-term. That indicates us that even though the ECLs of most of the firms are between 0.4% and 0.8%, extreme ECL are more frequent than small ECLs. Below 2°C Immediate is the least displaced distribution. We can see that in the short- and medium-term its distribution is slightly displaced towards greater loss compared to the baseline. This is caused by the policies implemented from 2020. However, the orderly and immediate transition allows firms to slowly adapt and it seems that in the long-term ECL converge to the baseline distribution.

Net-Zero 2050 shows the biggest displace to the right for all the horizons analyzed. It also becomes flatter and has heavier tails as the years go by, which means there is more dispersion between ECLs of the firms and extreme values of ECL are more frequent, reaching up to 1.4%. Finally, Below 2°C Delayed scenario suffers a shock in the medium-term, where the Kernel function displaces to the left. In the long-term, ECL continue increasing and the right tail becomes heavier, indicating larger ECLs for some firms.

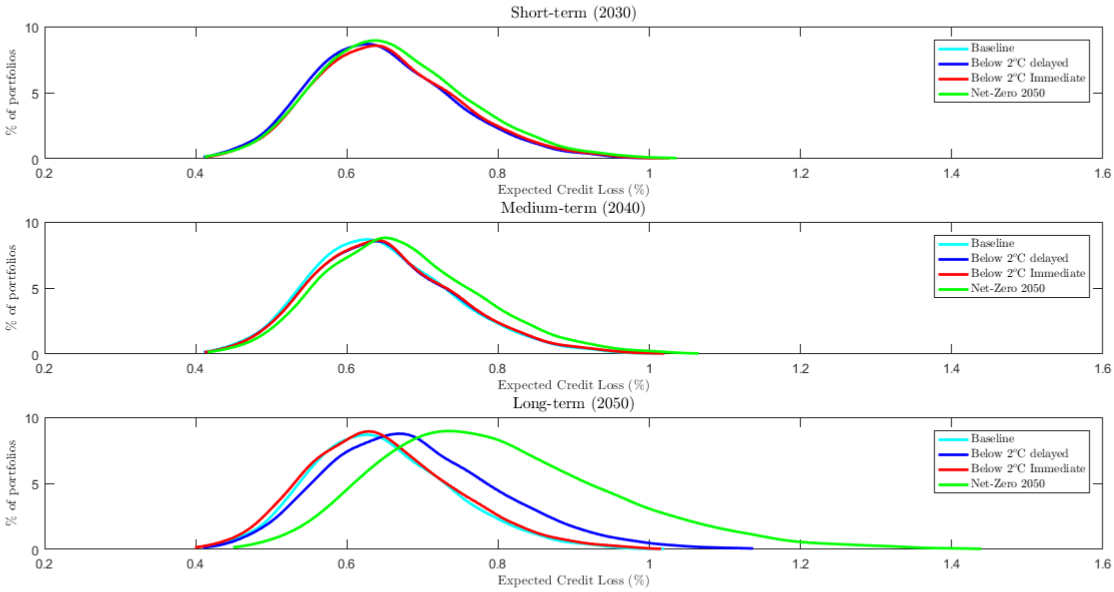

Figure 3.13: Kernel function of the portfolios' ECLs.

Chapter 4

Conclusions

Despite the challenging and demanding modelling issues that we are facing, climate change is an crucial key feature that should be considered in risk management due to its impact on the financial stability. Transition risk deals with the potential changes in financial risks that might arise from the transition towards a low-carbon economy. Credit risk could be affected throught some policies implemented for the transition, such as carbon taxes, the need of technological innovation or changes in preferences of the customers. Our aim is to analyze the impact of different transition scenarios on the credit risk of a portfolio made up of SMEs.

The results obtain in the empirical exercise are similar to the ones reported by the Bank of Canada (Hossini, H. *et al.*, 2022 [26]). Nevertheless, compared to Hossini *et al.* (2022), our results present a bigger impact on crops and a higher resilience of coal and livestock sectors. The highly exposed sectors are crops, refined oil products and oil & gas. Instead, the sector that show to be least harmed are electricity and commercial transportation. Moreover, the impact from Below 2°C Immediate scenario on credit risk is smoother than than the other scenarios, since policy is implemented immediately and progressively which allows firms to progressively adapt. Below 2°C Immediate and Net-Zero 2050, both scenarios cause sharper shock in the PDs and LGDs of the borrowers due to more restrictive policy being implemented. The former implements policy late, while in the latter aims a lower temperature by 2050.

Throughout the paper we faced some challenges. First, there is very limited data available to measure climate-credit relations. That leads to the need for a great number of assumptions and proxies. In order to introduce climate risks in entities' risk management, collection of climate related quality data should be required from now on. Nevertheless, a lot of SMEs cannot afford to generate climate data. Our work provides a framework approach to apply in those cases.

The methodology presented by the Bank of Canada (Hossini, H. *et al.*, 2022 [26]) and applied in this paper could be a good methodology to assess climate impacts on credit risk. It is compatible with different sectors and different scenarios, and it can be applied to different timeframes and RFPs. So, it is replicable, standard and improves as we get more borrowers and data, but also taylor-made. However, without available data, the reliability and utility of the results obtained is limited.

Moreover, the methodology outlined in the paper of the Bank of Canada some steps strongly depend on expert judgments and assumptions. Some steps can be approached in different ways and can lead to cherry-picking, so without the right resources and collaboration partners can be very difficult to carry out. Those steps, mostly Step 4 and 5, where the representative group of each segment and their impact on the PD is settled, vary widely across entities. That makes the results not comparable even not reliable. It is important to design a standard methodology that reduces the need of expert opinion and assumptions and makes the results more consistent and comparable.

4.1 Further research.

An assumption we make in this paper and that is very common among most of the climate risk pilot exercises carried out up to this day is that balance sheets are static. That means that financial entities do not take actions to hedge or mitigate their exposure to climate risks and all exposures remain unchanged for the life horizon. A static balance sheet avoids underestimating future potential financial impacts. That assumption may be suitable for banks with loans that keep unchanged for a long time or for short-time analysis horizons. However, for longer analysis horizons, static balance sheets are unrealistic since financial institutions are expected to increasingly adapt their balance sheet in line with climate-related risks. Financial institutions may try to reduce their exposure to transition risk redistributing their credit and reallocating assets from activities most affected by climate risks towards more sustainable sectors. Static balance sheets do not capture this type of reaction of the financial institutions. So it may lead to overestimating future potential risks.

In order to do a more realistic analysis, dynamic balance sheet adjustments could be considered. Dynamic balance sheets would allow financial entities to have a more accurate and smoother forecast of feasible future financial impacts of transition risks. Nevertheless, considering dynamic balance sheets adds complexity to the exercise since an extremely large number of additional assumptions, methodologies and data are needed. It also makes results less tractable and hinders the implementation of the methodology.

Furthermore, physical risk is not considered in this paper. We focus on quantifying transition risk impacts, but physical risks are not less important. In fact, transition risks and physical risk are complementary. High transition risks usually leads to low physical risks and vice versa. Extreme weather events are becoming more and more frequent and their impact is significant. So, it can be interesting to incorporate physical risks on the scenarios analyzed and try to understand possible consequences they may have, as well as possible interactions between transition and physical risks. That is, apart from the adverse scenarios considered in this paper, it could be interesting to consider scenarios that reach the temperature aims but evolve differently over the years.

Besides, the RFPs are uncertain and are not very granular. It could be interesting to estimate RFPs for more granular groups and geographies. In our case, we used the RFFs for Europe, but most of the portfolio of Laboral Kutxa is located in Spain. So, it can be interesting to design scenarios and estimate RFPs for Spain which could vary from the ones estimated for Europe as a whole. Once the most emission intensive sectors are analyzed, it could also be interesting to analyze more sectors. That would allow to see the effects climate risks could have in sectors with less emissions and it would be possible to analyze the impact on the whole loan portfolio. This would help banks to rethink their long-term lending strategy, for example by investing more in sectors with low PDs or offsetting increases in PD of some borrowers with decreases in others.

This paper highly relies on the work done by the BoC. We use the RFPs they estimated and we are based on their sectorization and segmentation. As more climate related data is available and more improvements are made, it could be possible to personalize more those steps.

So, due to its novelty and limitations, climate risks is a challenge that will require a significant effort for the banking sector. However, it will be a fundamental tool to move forward in the low emission transition to achieve the temperature aims.

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Appendix A

Models' full name:

- 2DII: 2 Degrees Investing Initiative - Paris Agreement Capital Transition Assessment (PACTA).
- CFIN: Battiston, Monasterolo and Mandel – CLIMAFIN – Climate Finance Alpha.
- CAME: Cambridge Econometrics – E3ME – FTT – GENIE.
- CISL: Cambridge Institute for Sustainability Leadership – ClimateWise Transition risk framework.
- CAR4: Carbone 4 – Carbon Impact Analytics (CIA).
- ISSE: ISS ESG – Portfolio Climate Impact Report and Raw Data.
- MSCI: Carbon Delta/MSCI Climate Value-at-Risk Tool (Climate VaR).
- OLWY Oliver Wyman – Climate Transition Risk Methology.
- ORTE: Ortec Finance – ClimateMAPS.
- PWC: PwC/The CO-Firm – Climate Excellence.
- RIGH: X-Degree Compatibility Model (XDC Model).
- SBTI: Science-based targets initiative – Science-based Target Setting (SBT) Tool and Sectoral Decarbonization Approach (SDA) Transport Tool.
- SPCM: S&P Global Market Intelligence – Climate Linked Credit Analytics for Upstream Oil & Gas Companies.
- SPPD: S&P Global Market Intelligence – Climate Linked Credit Risk Tool.
- UNIA: University of Augsburg – Carbon Risk Management (CARIMA).
- VIVE: Vivid Economics – Climate Risk Toolkit.

Model	Access	Objective	Output metrics	Time Horizonte	Granularity	Transparency	Scenarios	Coverage	Risk indicators
2DII	Public, free access	Measure the alignment of financial portfolios with 2°C decarbonization pathways. Maps forecasted macroeconomic trends and shocks into financial portfolio impacts.	• Technology or Sector Exposure. • Deviation from climate alignment. • Climate pathways (temperature range) per unit of production level.	1-year steps within 5 years.	Country and most emission intensive sectors differentiated.	• Code publicly available on Github. • Data sources available online. • Model structure and assumptions documented.	Scenario neutral.	• Equity and bond issuers. • Transition risk sources scenario neutral and adaptable. • Is possible to cover physical risks.	• Emission intensity and absolute emissions. • Production capacity. • Peer-comparisons analysis of indicators.
CFIN	Public model, customized analyses at individual costs	Estimate the propagation of climate shocks towards firms and the resulting impacts on financial assets. Introduces forward-looking climate scenarios in valuation of counterparty risk.	• Expected loss. • VaR. • Conditional VaR. • Change in PD.	Fully flexible.	Country and climate-policy relevant sectors differentiated.	• Code available upon request for scientific use. • Data sources reported. • Model structure and assumptions available.	Scenario neutral. Default: IEA	• Transition risk sources adaptable to users´ beliefs and expectations. • Physical risks if data is available for assets under consideration. • Trade-off physical-transition if a scenario is available.	• EBITDA per business segments. • Segment exposure to climate policy.

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (1/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Model	Access	Objective	Output metrics	Time Horizon	Granularity	Transparency	Scenarios	Coverage	Risk indicators
CAME	Public model, customized analyses at individual costs.	Provide estimates of impacts of the policies on the global economy, energy consumption and the take up rates of the new technologies and emissions using as inputs the policy shocks which form the scenarios. It's a macroeconomic simulation model.	• Macroeconomic and sectoral economic impacts (volumes and prices). • Energy consumption by sectors and fuels. • Sectoral CO_2 emissions.	1-year time steps, model runs up to 2100.	Country and sector differentiated (can track financial flows between NACE economic sectors).	• Some parts of the code have restricted Access and other parts are open Access upon request. • Data sources EDGAR database. • Full documentation available on the underlying model and assumptions.	Scenario neutral and user specific. Usually IEA scenarios.	• Transition risk sources adaptable to users´ beliefs and expectations. • Physical risks covered by aggregating damage functions.	• Absolute emissions converted to temperature change (GENIE model). • Emission intensity.
CISL	Public, free access.	Identify the material financial impacts from transition risks across a large portfolio, assess the financial impact from low carbon transition at an asset-by-asset level and incorporate the potential impacts of transition risk directly into investors' own financial models.	• Percentage change in financial drivers.	Can be adapted to cover any year but focuses on 2020, 2030 and 2040 to cover as broad a range of investment horizons as possible.	Considers USA, EU and India and is sector differentiated (power assets, fuel infrastructure, public buildings, utilities, transportation and logistics, information and communication, water supply, sewage, waste management…).	• Code not available. • Data partially reported. • Baseline assumptions and scenario underlying this tool could be found in CISL.	Range of scenarios to choose from IEO (WEO and ETP), IPCC and others.	• Focuses on infrastructure investments and can be applied to an array of global infrastructure asset types. • Transition risk sources adaptable (covers emerging policy and legal requirements, market and technology shifts…) • Physical risk module available.	• Comparison of impact of financial drivers on assess risk exposure of specific sectors and geographies due to climate scenarios.

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (2/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Model	Access	Objective	Output metrics	Time Horizon	Granularity	Transparency	Scenarios	Coverage	Risk indicators
CAR 4	Public, paywall, fixed price and customized options.	• Measure GHG emissions induced by investment on underlying firms'. • Measure how underlying firms are contributed to and/or compatible with decreasing world-wide carbon emissions. • Evaluate the evolution of the carbon impact of the underlying firms in the coming years. • Report on the carbon impact of portfolios and pilot of investment strategy.	• Induced emissions and savings scope 1-3, financial carbon intensity. • Forward-looking strategy, rating and alignment with the 2°C trajectories. • Specific indicators: Green and brown shares, energy consumption/ production mix, fossil fuel reserves…	1-year time steps.	Bottom-up approach, each asset is analysed individually before consolidating the results at portfolio level. Country and sector differentiated, focused on "high stakes" sectors.	• Private code. • Data sources reported. • Model structure, scenarios and assumptions partially reported.	IEA ETP scenarios.	• Smooth and shock transitions in policy, market upstream, market downstream, technology… • Physical risks partially covered.	• Absolute emissions, emission intensity and production capacity emissions. • Peer comparison. • Transition readiness: avoided emissions, green share, strategic orientation • Brown shares…
ISSE	Public, paywall, fixed price and customized options.	Support investors who want to comply with key disclosure frameworks and indicate how a company is managing its industry-specific climate risks.	• Portfolio GHG emissions scope 1-3. • Transition risk analysis. • Physical risk analysis. • Scenario analysis on 2, 4 and 6°C of warming.	Extends to 2050.	Sector differentiated per default by The Carbon Risk Rating.	• Code not available. • Data sources self-reported. • Model structure, scenarios and assumptions partially reported	IEA ETP scenarios.	• Equity and fixed income portfolios. • Transition risk sources adaptable outside policy, risks in supply chain, risks in a firm's products and services, technology risks… • Physical risk covered as a separated output.	• Absolute emissions and emission intensity. • Production capacity emissions. • Transition readiness as Carbon Risk Rating.

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (3/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Model	Access	Objective	Output metrics	Time Horizon	Granularity	Transparency	Scenarios	Coverage	Risk indicators
MSCI	Public, paywall, fixed price and customized options.	Provide a forward-looking and return-based valuation assessment to measure climate related risks and opportunities in an investment portfolio. Provides insights into the potential climate-stressed market valuation of investment portfolios and downside risks.	• VaR on asset price, issuer level costs and other intermediate metrics.	1-year and 5-year time steps.	Country and sector differentiated taking into account 51 emissions related and 30 extreme weather related sectors.	• Private code. • Data sources reported as own estimates. • Model structure, scenarios and assumptions reported for tool users only.	REMIND (PIK) and scenario neutral for various SSPS from REMIND.	• Smooth transition in policy and technology. • Physical risks due to extreme weather.	• Absolute emissions and emissions intensity as emissions / revenue. • Industry peers comparison.
OLWY	Customized consulting services.	Help banks assess the transition-related exposures and identify the impact in credit risk in their corporate loan portfolios in potential policy and technology related impacts of a low-carbon transition. Allows to compute, through climate scenarios, direct and indirect emission costs, low-carbon CAPEX, change in revenues and segment sensitivities to risk factors.	• PD. • Rating. • Expected loss.	Annual time steps from today until 2060.	User-specific country and sector differentiated.	• Private code. • Data provided by IAMC and use of proxy. • Model structure, scenarios and assumptions partially reported.	REMIND (PIK) and MESSAGEix -GLOBIOM (IIASA)	• Smooth and shock transitions in policy, market upstream, market downstream, technology…	• Absolute emissions and emission intensity. • Production capacity. • Transition readiness.

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (4/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Model	Access	Objective	Output metrics	Time Horizon	Granularity	Transparency	Scenarios	Coverage	Risk indicators
ORTE	Private tool, access requires either datasets subscription or one-off report delivery contract.	Quantify risks and opportunities associated with climate change into traditional forward-looking financial scenarios sets that drive strategic investment decision-making and analyse the impacts of various global warming pathways on investors' balance sheet simulation.	• Quantified climate risk-aware economic and financial outlooks. • Macroeconomic impacts such as GDP, interest rates… • Impact on asset classes performance. • Fund total impact. • Various metrics: bankruptcy, underfunding …	Annual time steps up to 2100 differentiating impact between short- (now-2030), medium- (2030-2050) and long-term (2050+).	Country differentiated for some countries and sector differentiated based on the GICS classification.	• Code available to clients if a yearly subscription is purchased. • Data sources partially reported and estimated by Cambridge Econometrics (publicly available). • Model structure, scenarios and assumptions reported.	Three climate scenarios: Paris Orderly Transition, Paris Disorderly Transition and Failed Transition.	• Smooth and shock transition risk sources adaptable to users' beliefs and expectations covering disruptive policy and financial shock, market pricing… • Physical risks covered. • Trade-off physical-transition risks covered.	• Transition risk exposure measured by looking how policy and technology drivers impact broader macroeconomic interactions worldwide and how this outlook in turn impacts the portfolio's risk exposure (top-down approach)
PWC	Public, paywall, customized.	Provide a forward-looking financial assessment of climate related risks and opportunities and enable the assessment of risks also from market and competitive dynamics, technological advancements, and regulations that also extend beyond carbon prices. (Bottom-up)	• Change in EBITDA. • Change in EBIT. • Change in CAPEX sales. • Change in volume and other financial KPIs as applicable.	2025, 2030, 2040, 2050.	Partially country differentiated in seven world regions and sector differentiated by NAICS and mapped by the TCFD.	• Private code. • Data sources reported (own databases and third-party databases). • Full transparency on model structure, scenarios and assumptions.	Range of IEA scenarios to choose from.	• Smooth transition risk sources such as policy (carbon pricing, taxation…), market upstream (input prices, supply cost…) market downstream (changes in demand, reputation… and technology covered.	• Emission intensity. • Production capacity. • Peer comparison. • Transition readiness. • Sector specific indicators. • Market impact and market allocation logic.

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (5/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Model	Access	Objective	Output metrics	Time Horizon	Granularity	Transparency	Scenarios	Coverage	Risk indicators
RIGH	Public, fee access; XDC baseline, target and sector; public customized paywall.	Assess the climate impact of an economic entity such as company, a portfolio or a country with a bottom-up approach.	• Means of a Metric: the XDC.	Fully flexible, results displayed for 2050.	Country and sector differentiated in manual analysis.	• Code freely accessible for researchers through right. • Data sources reported in the academic article. • Model structure, scenarios and assumptions publicly available online Handbook.	Scenario neutral. Default: Target XDCs.	• Smooth and shock transitions in policy, market upstream, market downstream, technology… if scenario available.	• Absolute emissions and emission intensity. • Peer comparison. • Target XDCs.
SBTI	Public, free access.	Provide companies with advice on by how much and how quickly they need to reduce their GHG emissions in order to be consistent with climate goals.	• % reduction of absolute emissions and carbon intensity in selected target year. • Economic carbon intensity denominator in tCO_2/USD of value added. • Custom physical intensity denominator in tCO_2/custom physical unit.	Depending on user-specific target year.	Sector differentiated	• Code not publicly available. • Data user self-reported. • Model structure, scenarios and key assumptions reported.	Scenarios from IAMC and IEA.	• None as it isn't a risk tool, just a target tool.	• Absolute emissions in tCO_2 and emission intensity.

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (6/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Model	Access	Objective	Output metrics	Time Horizon	Granularity	Transparency	Scenarios	Coverage	Risk indicators
SPCM	Public, paywall, customized.	Enable investors and risk managers at banks and non-financial corporations to estimate the impact a carbon tax on companies operating in an upstream Oil & Gas sector. It translates the impact of a climate scenario on four drivers (volume, price, unit cost and capital expenditure) at an individual company level (bottom-up approach).	• Full company-level financial statements. • Current and future PD. • Current and future credit score. • Absolute and relative contribution of credit risk factors.	User can specify. Default: 1-year time steps and a 3-year horizon.	Country differentiated and Oil & Gas sector developed.	• Private code, tool users only. • Data sources reported: EIA data, self-reported and own estimations. • Model structure, scenarios and assumption partially reported.	REMIND (PIK) scenarios.	• Smooth and shock transition sources such as adaptable policies and market upstream and market downstream (via elasticity of demand and supply) are covered.	• Absolute emissions and cost of emissions.
SPPD	Public, paywall, customized.	Leverage Trucost's extensive database of CO_2 emissions at company level, project future market capitalization of public companies globally and determine the change in creditworthiness of those companies via structural Merton model.	• Company-level current and future earnings. • Current and future market capitalization. • Current and future distance to default. • Current and future PD. • Change in credit score	1-year time steps between 2020-2025 and 5-year time steps between 2025-2050.	Country and sector differentiated.	• Private code, available for users only. • Data provided by Trucost. • Model structure, scenarios and assumptions reported, paying users can see all inputs, drivers and formulas and final outputs.	Tool itself does not employ scenarios, but inputs on emission and cost projections for various scenarios from McKinsey and Trucost.	• Smooth and shock transition with sources such as policy and technology (cost to adopt new technology) are covered.	• PD and credit score calculated using future market capitalization. • Absolute emissions and emission intensity. • Peer comparison (average emission intensity). • Transition readiness (CAPEX)

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (7/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Model	Access	Objective	Output metrics	Time Horizon	Granularity	Transparency	Scenarios	Coverage	Risk indicators
UNIA	Public, free access.	Categorize firms as brown or green using a composite measure of three indicators designed to separately capture the sensitivity of firms' "value chains", of their "public perception" and of their "adaptability" to carbon risk.	• Carbon beta	Fully flexible.	Not necessary country and sector differentiation as investor expectations reflected in asset price.	• Code available on request by e-mail. • Data sources reported: CDP, Thomson Reuters7Refinitiv ESG, MSCI ESG, Sustainalytics. • Model structure, scenarios and assumptions and possibilities to adapt them reported in the manual.	Not scenario based.	• Transition risk sources based on capital market expectations such as Paris Agreement-like events and policies, green technologies, change in consumer behaviour towards green products…	• Carbon beta • Firm-level determinants of brown and green.
VIVE	Public, paywall, customized.	Use scenario analysis and microeconomic modelling to quantify the transition and physical risk impacts of disruptive climate policy on financial markets and create scenarios that best reflect clients' views given policy, technology and physical uncertainties. (Bottom-up)	Vary by asset class, but are generally provided in terms of valuation impacts.	Fully flexible, 1-year time steps.	Country and sector differentiated.	• Code available for clients only. • Data sources reported: Trucost or CDP. • Model structure, scenarios and assumptions communicated in final reports / method documentation for clients.	Scenario neutral using Vivid's inhouse scenario design tool.	• Smooth and shock transitions in policy, market upstream, market downstream, technology… covered and adaptable to users' beliefs and expectations. • Physical risks covered. • Trade-off physical-transition covered.	• Change in valuation. • Emission intensity. • Peer comparison. • Transition readiness (abatement potential based on cost curves).

Table A.1: In-depth descriptive analysis of 16 existing climate models that translate climate scenarios into economic and financial impacts. (8/8) (*Source: Bingler, J. A. and Colesanti Senni, C., 2020 [11]*)

Appendix B

CNAE code (2 digits)	Description CNAE sector	Equivalent NAICS code	Description of the equivalent NAICS sector	Equivalent sector in our data
01 (011,012)	Crop and animal production, hunting and related service activities	11	Agriculture, Forestry, Fishing and Hunting	Crops
01 (014)				Livestock
01 (013,016,017)				-
02	Forestry and logging	11	Agriculture, Forestry, Fishing and Hunting	Forestry
03 (031)	Fishing and aquaculture	11	Agriculture, Forestry, Fishing and Hunting	-
03 (032)				Livestock
05	Mining of coal and lignite	21	Mining, Quarrying, and Oil and Gas Extraction	Coal
06	Extraction of crude petroleum and natural gas	21	Mining, Quarrying, and Oil and Gas Extraction	Oil & Gas
07	Mining of metal ores	21	Mining, Quarrying, and Oil and Gas Extraction	Others
08	Other mining and quarrying	21	Mining, Quarrying, and Oil and Gas Extraction	Others

Table B.1: Equivalent NAICS code for each of the CNAE codes in the portfolio and their classifications in the sectors defined by the Bank of Canada. (1/6) (*Source: Eurostat*)

CNAE code (2 digits)	Description CNAE sector	Equivalent NAICS code	Description of the equivalent NAICS sector	Equivalent sector in our data
09 (091)	Mining support service activities	21	Mining, Quarrying, and Oil and Gas Extraction	Oil & Gas
09 (099)				Coal
10	Manufacture of food products	31-33	Manufacturing	FOOD
11	Manufacture of beverages	31-33	Manufacturing	FOOD
12	Manufacture of tobacco products	31-33	Manufacturing	FOOD
13	Manufacture of textiles	31-33	Manufacturing	Others
14	Manufacture of wearing apparel	31-33	Manufacturing	Others
15	Manufacture of leather and related products	31-33	Manufacturing	Others
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	31-33	Manufacturing	Others
17	Manufacture of paper and paper products	31-33	Manufacturing	Energy-intensive industries
18	Printing and reproduction of recorded media	31-33	Manufacturing	Energy-intensive industries
19	Manufacture of coke and refined petroleum products	31-33	Manufacturing	Refined Oil Products
20	Manufacture of chemicals and chemical products	31-33	Manufacturing	Energy-intensive industries
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	31-33	Manufacturing	Energy-intensive industries
22	Manufacture of rubber and plastic products	31-33	Manufacturing	Energy-intensive industries
23	Manufacture of other non-metallic mineral products	31-33	Manufacturing	Energy-intensive industries
24	Manufacture of basic metals	31-33	Manufacturing	Energy-intensive industries

Table B.1: Equivalent NAICS code for each of the CNAE codes in the portfolio and their classifications in the sectors defined by the Bank of Canada. (2/6) (*Source: Eurostat*)

CNAE code (2 digits)	Description CNAE sector	Equivalent NAICS code	Description of the equivalent NAICS sector	Equivalent sector in our data
25	Manufacture of fabricated metal products, except machinery and equipment	31-33	Manufacturing	Energy-intensive industries
26	Manufacture of computer, electronic and optical products	31-33	Manufacturing	Others
27	Manufacture of electrical equipment	31-33	Manufacturing	Others
28	Manufacture of machinery and equipment n.e.c.	31-33	Manufacturing	Others
29	Manufacture of motor vehicles, trailers and semi-trailers	31-33	Manufacturing	Others
30	Manufacture of other transport equipment	31-33	Manufacturing	Others
31	Manufacture of furniture	31-33	Manufacturing	Others
32	Other manufacturing	31-33	Manufacturing	Others
33	Repair and installation of machinery and equipment	81	Other Services (except Public Administration)	SERV
35 (351)	Electricity, gas, steam and air conditioning supply	22	Utilities	Electricity
35 (3521)				Energy-intensive industries
35 (3522)				Gas
35 (3523,353)				Others
36	Water collection, treatment and supply	22	Utilities	Others
37	Sewerage	22	Utilities	Others
38	Waste collection, treatment and disposal activities; materials recovery	56	Administrative and Support and Waste Management and Remediation Services	SERV
39	Remediation activities and other waste management services	56	Administrative and Support and Waste Management and Remediation Services	SERV
41	Construction of buildings	23	Construction	Others
42	Civil engineering	23	Construction	Others

Table B.1: Equivalent NAICS code for each of the CNAE codes in the portfolio and their classifications in the sectors defined by the Bank of Canada. (3/6) (*Source: Eurostat*)

CNAE code (2 digits)	Description CNAE sector	Equivalent NAICS code	Description of the equivalent NAICS sector	Equivalent sector in our data
43	Specialized construction activities	23	Construction	Others
45	Wholesale and retail trade and repair of motor vehicles and motorcycles	42	Wholesale Trade	SERV
46	Wholesale trade, except of motor vehicles and motorcycles	42	Wholesale Trade	SERV
47	Retail trade, except of motor vehicles and motorcycles	44-45	Retail Trade	SERV
49 (491-494)	Land transport and transport via pipelines	48-49	Transportation and Warehousing	Commercial Transportation
49 (495)				Oil & Gas
50	Water transport	48-49	Transportation and Warehousing	Commercial Transportation
51	Air transport	48-49	Transportation and Warehousing	Commercial Transportation
52	Warehousing and support activities for transportation	48-49	Transportation and Warehousing	Commercial Transportation
53	Postal and courier activities	48-49	Transportation and Warehousing	Commercial Transportation
55	Accommodation	72	Accommodation and Food Services	SERV
56	Food and beverage service activities	72	Accommodation and Food Services	SERV
58	Publishing activities	51	Information	SERV
59	Motion picture, video and television programme production, sound recording and music publishing activities	51	Information	SERV
60	Programming and broadcasting activities	51	Information	SERV
61	Telecommunications	51	Information	SERV
62	Computer programming, consultancy and related activities	54	Professional, Scientific, and Technical Services	SERV
63	Information service activities	51	Information	SERV

Table B.1: Equivalent NAICS code for each of the CNAE codes in the portfolio and their classifications in the sectors defined by the Bank of Canada. (4/6) (*Source: Eurostat*)

CNAE code (2 digits)	Description CNAE sector	Equivalent NAICS code	Description of the equivalent NAICS sector	Equivalent sector in our data
64	Financial service activities, except insurance and pension funding	52	Finance and Insurance	SERV
64 (6420)		55	Management of Companies and Enterprises	SERV
65	Insurance, reinsurance and pension funding, except compulsory social security	52	Finance and Insurance	SERV
66	Activities auxiliary to financial services and insurance activities	52	Finance and Insurance	SERV
68	Real estate activities	53	Real Estate and Rental and Leasing	SERV
69	Legal and accounting activities	54	Professional, Scientific, and Technical Services	SERV
70 (7021 & 7022)	Activities of head offices, management consultancy activities	54	Professional, Scientific, and Technical Services	SERV
70 (7010)		55	Management of Companies and Enterprises	SERV
71	Architectural and engineering activities; technical testing and analysis	54	Professional, Scientific, and Technical Services	SERV
72	Scientific research and development	54	Professional, Scientific, and Technical Services	SERV
73	Advertising and market research	54	Professional, Scientific, and Technical Services	SERV
74	Other professional, scientific and technical activities	54	Professional, Scientific, and Technical Services	SERV
75	Veterinary activities	54	Professional, Scientific, and Technical Services	SERV
77	Rental and leasing activities	53	Real Estate and Rental and Leasing	SERV
7732		23	Construction	Others
78	Employment activities	56	Administrative and Support and Waste Management and Remediation Services	SERV
79	Travel agency, tour operator and other reservation service and related activities	56	Administrative and Support and Waste Management and Remediation Services	SERV

Table B.1: Equivalent NAICS code for each of the CNAE codes in the portfolio and their classifications in the sectors defined by the Bank of Canada. (5/6) (*Source: Eurostat*)

CNAE code (2 digits)	Description CNAE sector	Equivalent NAICS code	Description of the equivalent NAICS sector	Equivalent sector in our data
80	Security and investigation activities	56	Administrative and Support and Waste Management and Remediation Services	SERV
81	Services to buildings and landscape activities	56	Administrative and Support and Waste Management and Remediation Services	SERV
82	Office administrative, office support and other business support activities	56	Administrative and Support and Waste Management and Remediation Services	SERV
84	Public administration and defense; compulsory social security	92	Public Administration	SERV
85	Education	61	Educational Services	SERV
86	Human health activities	62	Health Care and Social Assistance	SERV
87	Residential care activities	62	Health Care and Social Assistance	SERV
88	Social work activities without accommodation	62	Health Care and Social Assistance	SERV
90	Creative, arts and entertainment activities	71	Arts, Entertainment, and Recreation	SERV
91	Libraries, archives, museums and the other cultural activities	71	Arts, Entertainment, and Recreation	SERV
92	Gambling and betting activities	71	Arts, Entertainment, and Recreation	SERV
93	Sports activities and amusement and recreation activities	71	Arts, Entertainment, and Recreation	SERV
94	Activities of membership organizations	81	Other Services (except Public Administration)	SERV
95	Repair of computers and personal and household goods	81	Other Services (except Public Administration)	SERV
96	Other personal service activities	81	Other Services (except Public Administration)	SERV
97	Activities of households as employers of domestic personnel	81	Other Services (except Public Administration)	SERV
98	Undifferentiated goods- and services-producing activities of private households for own use	81	Other Services (except Public Administration)	SERV
99	Activities of extraterritorial organizations and bodies	92	Public Administration	SERV

Table B.1: Equivalent NAICS code for each of the CNAE codes in the portfolio and their classifications in the sectors defined by the Bank of Canada. (6/6) (*Source: Eurostat*)

Sector	NAICS	NACE
LIVE	112	014, 015, 032
FORS	113	02
CROP	111	011, 012, 015
COAL	2121, 213117, 213119	05, 099
OIL	213111, 213118, 2111	06, 0910,495
GAS	2212, 213111, 213118, 2111	3522, 06, 0910,495
ELEC	2211	351
HYDRO	221111	3515
NUCLEAR	221113	3517
FOSSIL FUELS	221112	3516
OTHER (i.e., geothermical, solar, tidal, wind)	221119	3518, 3519
TRAN	488, 492, 481, 493, 483, 487, 486, 482, 485, 484	52, 53, 51, 50, 491,492,493,494
EINT	322, 323, 325, 326, 327, 331, 332	17, 18, 20, 21, 22, 23, 24, 25, 3521
FOOD	311, 312	10, 11, 12
ROIL	324	19
OTHR	339, 334, 336, 333, 2122, 2123, 314, 315, 316, 335, 321, 238, 236, 237, 2213, 337, 313, 213117, 213119	32, 26, 29, 30, 28, 07, 08, 13, 14, 15, 27, 16, 43, 41, 42, 36, 37, 353, 31, 09, 3523
SERV	541, 561, 611, 517, 448, 518, 522, 523, 441, 447, 515, 519, 711, 713, 721, 443, 453, 532, 811, 452, 551, 812, 813, 623, 624, 722, 814, 446, 562, 445, 621, 622, 442, 444, 451, 524, 454, 712, 521, 533, 115, 491, 531, 413, 414, 419, 526, 911, 912, 913, 914	69, 70, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82, 85, 61, 477, 4782, 6311, 451, 453, 473, 60, 639, 90, 91, 92, 93, 55, 474, 95, 33, 452, 454, 702, 96, 94, 87, 88, 56, 98, 86, 38, 39, 472, 475, 476, 65, 66, 479, 64, 68, 016, 4617, 463, 4615, 464, 4616, 465, 84

Table B.2: NAICS and NACE codes included in each of the sectors defined by the Bank of Canada.
(*Source: Hossini, H. et al., 2022 [26]*)

Sectors	Segments	NACE code	Number of SMEs	
1) Livestock	1) Livestock	014,032	377	377
2) Forestry	2) Forestry	02	80	80
3) Crops	3) Crops	011,012	173	173
4) Coal	4) Coal	05,099	26	26
5) Refined oil products	5) Refined oil products	19	5	5
6) Oil & Gas	6) Extraction of crude petroleum and natural gas	06	18	76
	7) Support activities for petroleum and natural gas extraction	091	5	
	8) Transport via pipeline	495	9	
	9) Distribution of gaseous fuels through mains	3522	44	
7) Electricity	10) Fossil-fuel electric power generation	3516	11	549
	11) Hydro and nuclear electric power generation	3515,3517	12	
	12) Other renewables electric power generation	3518,3519	418	
	13) Transmission, distribution and trade of electricity	3512,3513,3514	108	
8) Energy-intensive industries	14) Manufacture of paper and paper products, printing and related support activities	17,18	158	1000
	15) Manufacture of chemicals and chemical products, manufacture of basic pharmaceutical products and pharmaceutical preparations, and manufacture of rubber and plastic products	20,21,22,3521	223	
	16) Manufacture of other non-metallic mineral products	23	80	
	17) Manufacture of basic metals and manufacture of fabricated metal products, except machinery and equipment	24,25	539	
9) Commercial transportation	18) Air transport	51	6	1000
	19) Rail transport	491,492	4	
	20) Water transport	50	10	
	21) Freight transport by road, transit and land passenger transportation, and other transportation (removal services, support activities for transportation, couriers and messengers, and warehousing and storage)	493,494,52,53	980	

Table B.3: Segmentation and number of SMEs in the portfolio.