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# Assessing Climate-Related Financial Risk: Guide to Implementation of Methods

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# Abstract

The Bank of Canada and the Office of the Superintendent of Financial Institutions completed a climate scenario analysis pilot project with the collaboration of six Canadian financial institutions. The project aimed to increase understanding of the financial sector's potential exposure to risks in transitioning to a low-carbon economy and to help build the capabilities of authorities and financial institutions in assessing climate-related risks. To support the broader financial-sector community in building these capabilities, this report provides detail on the methodologies the pilot used to assess credit and market risks, which were informed by the financial impacts generated by the climate transition scenarios. The method to assess credit risk combined top-down and bottom-up approaches. Variables from the climate transition scenarios were first translated into sector-level financial impacts. The financial institutions then used these impacts to estimate the implications on credit outcomes through borrower-level assessments. Using the transition scenarios' financial impacts, and the stressed credit outcomes, the project estimated a relationship between climate transition information and credit risk. This was used to calculate expected credit losses at the portfolio level. The method to assess market risk was solely top-down. Using the scenario analysis, the project used a dividend discount model to estimate sectoral equity revaluations, which it then applied to equity portfolio holdings.



*Topics: Climate change; Financial stability; Econometric and statistical methods; Credit and credit aggregates*
*JEL codes: C, C5, C53, C83, G, G1, G32*



# Résumé

La Banque du Canada et le Bureau du surintendant des institutions financières ont réalisé un projet pilote d'analyse de scénarios climatiques avec la collaboration de six institutions financières canadiennes. Le projet avait pour but d'améliorer la compréhension de l'exposition potentielle du secteur financier aux risques liés à la transition vers une économie à faibles émissions de carbone, et de créer la capacité pour les autorités et les institutions financières d'évaluer les risques climatiques. Afin d'aider le secteur financier dans son ensemble à développer cette capacité, le rapport explique de façon détaillée les méthodes utilisées dans le cadre du projet pour évaluer les risques de crédit et de marché, qui ont été établis à partir des incidences financières prévues dans les scénarios de transition climatique. La méthode qui a servi à évaluer le risque de crédit combinait des approches descendante et ascendante. Les variables des scénarios ont d'abord été exprimées en incidences financières sectorielles. Les institutions financières ont ensuite évalué les emprunteurs en se basant sur ces incidences pour estimer les implications pour leur situation de crédit. S'appuyant sur les impacts financiers des scénarios de transition et la situation de crédit en période de tensions, le projet a fourni des estimations de la relation entre la transition climatique et le risque de crédit. Ces estimations ont été utilisées pour calculer les pertes de crédit attendues dans les portefeuilles. La méthode employée pour évaluer le risque de marché faisait appel uniquement à une approche descendante. En se fondant sur l'analyse des scénarios, le projet a utilisé un modèle d'actualisation des dividendes pour estimer les réévaluations boursières sectorielles, qui ont ensuite été appliquées aux actions détenues dans les portefeuilles.

*Sujets : Changements climatiques; Stabilité financière; Méthodes économétriques et statistiques; Crédit et agrégats du crédit*
*Codes JEL : C, C5, C53, C83, G, G1, G32*

# Contents

# 1. Introduction

The physical impacts of climate change and the transition to a low-carbon, net-zero economy may pose large structural changes to the economy, resulting in significant macroeconomic and financial system effects. While global efforts to decarbonize economies to reduce climate-related physical risks create opportunities for innovation and investment, they also carry transition risks. Transition risks arise in the financial system as it adapts to the shift to a low-carbon economy and changes in climate policy and regulation, technology, and consumer and investor preferences. Such changes, if unanticipated, can cause sudden revaluation of assets and reassessment of projected earnings, both in carbon-intensive sectors and in sectors connected to them through supply chains. This abrupt asset repricing could have large implications for a wide range of financial institutions that have significant exposures to these sectors, with potential consequences for financial stability.

Transition risks are of particular significance for Canada given its endowment of carbon-intensive commodities, the current importance of some of these carbon-intensive sectors for the Canadian economy, and the country's unique needs as a vast northern country for heating and transportation.[1] Timely and clear climate policy direction and the correct pricing of risks, supported by climate-related financial disclosures, contribute strongly to mitigating these risks.

The Bank of Canada and the Office of the Superintendent of Financial Institutions (OSFI) completed a climate scenario analysis pilot project to better understand the risks to the financial system that could arise from a transition to a low-carbon economy. The project involved the collaboration of six Canadian federally regulated financial institutions, including two banks, two life insurers and two property and casualty insurers.[2] The objectives of the pilot were to:

- build the capability of authorities and financial institutions for climate scenario analysis and support the Canadian financial sector in enhancing the disclosure of climate-related risks
- increase authorities' and financial institutions' understanding of the financial sector's potential exposure to risks that may come with a transition to a low-carbon, net-zero economy
- improve authorities' understanding of financial institutions' governance and risk management practices around climate-related risks and opportunities

To this end, the Bank developed a set of climate transition scenarios that explore pathways consistent with achieving global climate targets. This Bank of Canada technical report describes in detail the pilot's credit risk and market risk methodologies used to assess climate-related transition risk based on the pilot's scenarios. The report is intended to be used as a guide, with the goal of providing the broader financial sector community with useful information on the application of methodological tools and techniques related to scenario analysis. Our hope is that this information supports the financial sector's own efforts to assess and disclose climate-related transition risk through the development of resources and building capacity.

[1] The assessment of physical risks of climate change and the interaction between physical and transition risks are equally important. The Bank will be turning to these areas soon.

[2] Pilot participants were TD Bank Group, Royal Bank of Canada, Intact Financial Corporation, Manulife, Sun Life Financial and the Co-operators Group Limited.

This technical report accompanies the release of two other related reports. The first is the final report on the climate scenario analysis pilot project conducted by the Bank and OSFI (Bank of Canada and OSFI 2022), which presents the project's overall results and lessons learned. The second is a Bank of Canada staff discussion paper (Chen et al. 2022) that describes in detail the development and results of the climate transition scenarios. In addition to these reports, the Bank is also publishing the climate scenario data developed for the pilot.[3] The methodologies outlined in this report provide guidance on how the published data can be used to assess the effects of climate-related transition risks on the portfolio of any financial institution.

This report is organized as follows. Section 2 provides an overview of the climate transition scenarios developed by the Bank that supported the development of the climate-related financial risk assessment methodologies, including details on scenario assumptions and the scope of the pilot. Sections 3 and 4 present the detailed analytical steps taken for the climate-related credit and market risk assessments, respectively. These sections also offer guidance and considerations to keep in mind when applying the risk assessment methodologies, including some lessons learned and methodological limitations and challenges. Section 5 provides some concluding remarks.

## 2. Using scenario analysis to assess climate-related transition risk

Assessing climate-related risks is challenging due in part to the inherent long-term horizon, as well as the high degree of uncertainty about future climate events and about how policy, technology and socio-economic factors might evolve. While the impacts are global and economy-wide in nature, they may vary across regions and sectors.

Scenario analysis is well suited to examine the complex features of climate change. The approach is designed to help identify potential risks in an environment of considerable uncertainty. Scenario analysis offers a flexible "what if" framework that can help a wide range of players better understand how climate-related factors could drive changes in the economy and the financial system. Scenario analysis is not a prediction or forecast; rather, it describes hypothetical but plausible future transition pathways.

In line with the objectives of the pilot project, the Bank developed a set of global climate scenarios related to the transition to a low-carbon, net-zero economy. The scenarios were intentionally designed to be adverse to capture a range of risk outcomes that could be stressful to the Canadian economy and the financial system. The financial institutions that participated in the pilot examined the potential risk exposures of selected elements of their balance sheets related to these transition scenarios. Specifically, the bank participants analyzed credit risks to their wholesale loans portfolio, while the insurers analyzed credit risk to their bonds and corporate loan portfolios and market risk to their equity portfolio.[4]

For tractability, financial institutions' balance sheets were assumed static as of the end of 2019 (i.e., institutions' portfolios are frozen in time). While providing less realism in the sense that financial institutions cannot mitigate risks through assumed management actions or deviate from current business models, the assumption of a static balance sheet made results tractable and eased implementation of the methodology. Notably, the approach requires users to make fewer assumptions and avoids the need for

[3] Data on the climate scenarios are available on the Bank website.

[4] The analysis focused mostly on Canadian and US exposures, with some institutions also analyzing their exposures outside of North America.

additional methodologies or data to project balance sheets forward, thereby also improving data reliability and consistency.[5]

To develop the climate transition scenarios, the Bank worked with the Massachusetts Institute of Technology (MIT) using its Economic Projection and Policy Analysis (EPPA) computable general equilibrium energy-economy model. The model provides important sectoral information relevant to the Canadian financial system, which was needed for the analysis of risks along the different transition pathways. The model tracks emissions as they relate to economic activity and has firms making cost-minimizing decisions over time.[6] The pilot focused on the 10 most emission-intensive sectors in the Canadian economy, accounting for approximately 68 percent of Canada's greenhouse gas emissions. These sectors are crops, forestry, livestock, coal, crude oil, gas, refined oil, electricity, energy-intensive industries and commercial transportation. Given that the transition can also play out differently across sectors, some of the sectors were disaggregated into subsectors or segments.[7]

The following briefly presents the narratives of the climate transition scenarios. It then outlines the methodological approach used to determine the financial impacts associated with those scenarios. These financial impacts represent critical components of the climate-related credit and market risk assessment methods presented later in the report.

### *Climate transition scenario narratives*

For this pilot, the Bank developed four global climate transition scenarios over a 30-year horizon, from 2020 to 2050, consistent with achieving stated climate targets. The Bank developed its own scenarios to provide economic and financial data at the relevant geographic and sectoral level of granularity to assess the exposures of Canadian financial institutions. The scenarios vary in terms of two key drivers of climate transition risk: first, the ambition and timing of global climate policy action; and second, the pace of technological change and availability of carbon dioxide removal technologies. As mentioned above, in line with the objectives of the pilot, the scenarios were purposely designed to capture a range of risk outcomes that could be stressful to the economy and the financial system. They are not meant to be forecasts or comprehensive. The four transition scenarios are the following, with the last three consistent with the Paris Agreement commitment of limiting global warming to below 2˚C[8]:

> **Baseline (2019 policies) scenario**—a baseline scenario consistent with global climate policies in place at the end of 2019, implying a continued rise in emissions and an increase in the average global warming in the range of 2.9–3.1°C by 2100

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[5] For a more detailed discussion on balance sheet assumptions in the context of the use of scenario analysis to assess climate transition risk, see ACPR (2020).

[6] The MIT-EPPA model provided projections of economic variables and emissions of greenhouse gases (and other air pollutants) across 14 sectors and 18 distinct countries and regions. To place the sector-level analysis in a larger macroeconomic context, the Bank used two of its macroeconomic policy models to analyze the impact on Canadian, US and global economies. These are the Terms-of-Trade Economic Model (ToTEM) III, the main structural model for the Canadian economy, and the BoC-GEM-FIN, a five-region model for the global economy.

[7] The disaggregation approach is presented in section 3.

[8] The 2015 Paris Agreement established a goal of holding the increase in global temperature within a range of 1.5–2.0°C above pre-industrial levels as well as a commitment to engage in adaptation planning and implementation. These goals were underscored by the recent Glasgow Climate Pact.

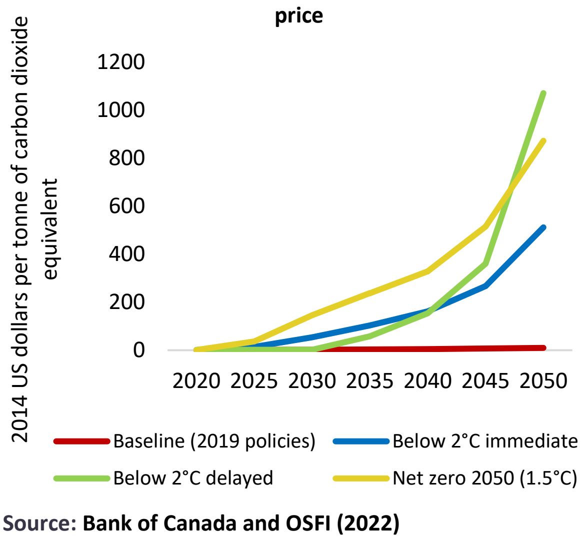
**Below 2˚C immediate scenario**—a global policy action scenario that begins immediately in 2020, aiming to limit the average global warming to below 2˚C by 2100

**Below 2˚C delayed scenario**—a global policy action scenario that also aligns with a 2˚C target but does not begin until 2030, after a decade of following 2019 policies

**Net-zero 2050 (1.5˚C) scenario**—A more ambitious immediate global policy action scenario to limit average global warming to 1.5°C. In this scenario, the pace of technological change is faster relative to the other scenarios, which assume a slow pace of technological progress. The faster pace of technological progress in this scenario partially eases the transition in other sectors of the economy and supports the achievement of the more ambitious global climate target. Also, a moderate amount of carbon dioxide removal technology is available, including bioenergy with carbon capture and storage.

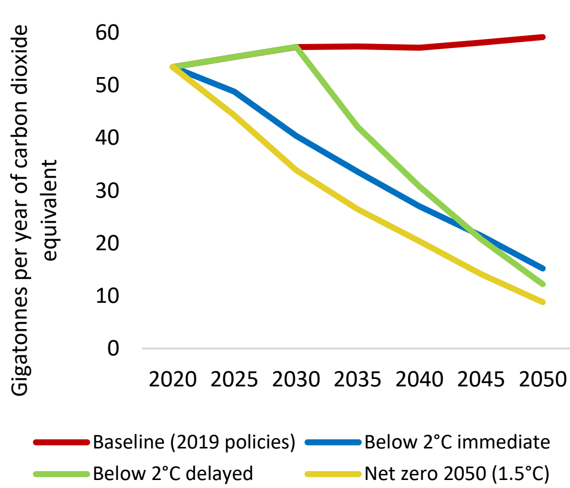
Charts 1 and 2 show the paths of global shadow carbon prices and global greenhouse gas emissions for the different scenarios up to 2050.[9] The below 2°C delayed scenario maintains the same target of limiting warming as that of the below 2°C immediate scenario, but it assumes global policy actions do not intensify until 2030. Delayed global policy action requires a steeper increase in the shadow price of carbon to meet the same level of climate ambition (**Chart 1**). Under delayed action, emissions must fall rapidly to make up for lost time (**Chart 2**), implying a sharper transition through mid-century. Comparing the net-zero 2050 (1.5°C) scenario with the below 2°C immediate scenario shows a front-loading of impacts to be consistent with the more ambitious target of limiting warming to 1.5°C.[10]

**Chart 1: Global GDP-weighted shadow carbon price**




**Source:** Bank of Canada and OSFI (2022)

**Chart 2: Global greenhouse gas emissions**




**Source:** Bank of Canada and OSFI (2022)

[9] The shadow price of carbon captures the remaining implicit climate policy action required to meet a pre-determined emissions target, beyond the policies that are explicitly included in the scenarios. For more details on the role of shadow prices as well as other details and assumptions on the scenarios, see Chen et al. (2022).

[10] The pilot's scenario narratives and the paths for global emissions and carbon prices are well-aligned with those of the scenarios developed by the Network for Greening the Financial System (NGFS), to which the Bank contributed. Please refer to the NGFS Scenarios Portal for more information.

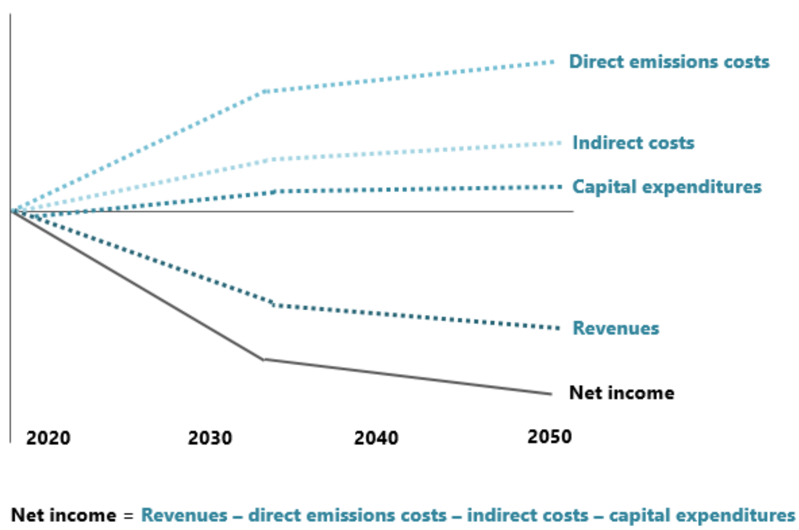
*Mapping scenario variables into financial impacts: Risk factor pathways*

An important output of the transition scenarios are the sectoral impacts. While every sector contributes to reducing emissions to meet climate targets, the scenarios reveal diverse impacts from the transition to a low-carbon economy. For example, fossil-fuel sectors (coal, oil, and gas) have sharper reductions in emissions to meet targets and are impacted by the transition away from these sectors. Other sectors, such as the electricity sector, go through a costly transition period of decarbonization before benefiting through electrification and limited exposure to climate policies. The reduction in emissions in each sector depends on various factors captured in the scenarios, including carbon prices, emission intensities of the sectors, the costs of fossil-fuel inputs and the availability and cost of low emissions technologies.

To measure the sectoral financial impacts associated with the transition scenarios, we mapped selected outputs from the scenarios into risk factor pathways (RFPs), reflecting drivers of net income. Specifically, the RFPs reflect changes of four components along the transition path and relative to the baseline (2019 policies) scenario (**Chart 3**).[11] The four components are:

- **direct emissions costs** (e.g., the increase in a sector's costs associated with the release of greenhouse gases from burning fossil fuels);[12]
- **indirect costs** (e.g., the increase in a sector's input costs as passed on from the increase in direct emissions costs from upstream sectors);
- **capital expenditures** (e.g., when a sector purchases new technologies to reduce its emissions); and
- **revenues** (e.g., when a sector experiences a reduction in demand because its product remains emission-intensive, causing its revenues to fall).

Chart 3: Illustrative evolution of the components of net income
(% change relative to baseline)




[11] Chart 3 receives inspiration from the "Sector-level risk factor pathways" chart in UNEP-FI, Oliver Wyman and Mercer (2018).

[12] Direct emissions costs are calculated by multiplying the sectoral emissions with carbon prices under each scenario.

As mentioned previously, the RFPs in the pilot project were calculated for the 10 most emission-intensive sectors of the economy (crops, forestry, livestock, coal, crude oil, gas, refined oil, electricity, energy-intensive industries, and commercial transportation).

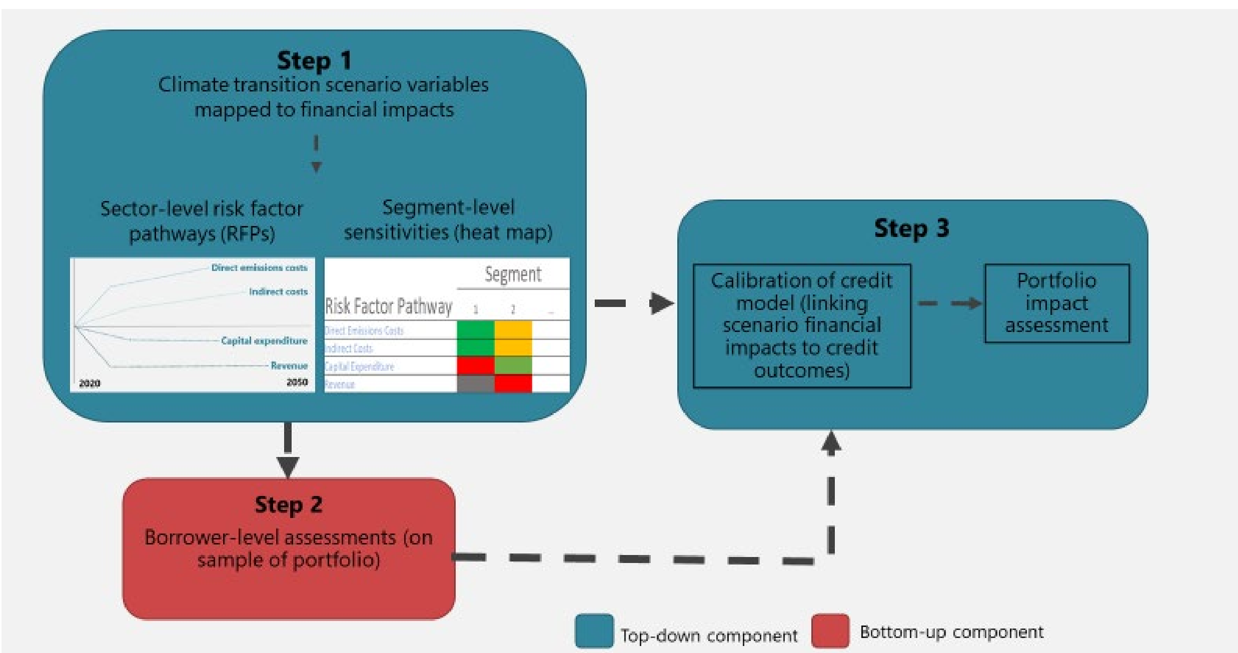
In both the credit risk analysis and the equity risk analysis (both of these are explained in the following section), the RFPs are used to estimate credit outcomes and equity valuations. Similar to the RFPs, the estimated credit outcomes and equity valuations were also measured as changes relative to the baseline (2019 policies) scenario. This ensured that the sources of the financial shock or stress in the exercise could be attributed mainly to the changes in climate policy and technology assumed in the transition scenarios.

# 3. Approach to assessing climate-related credit risk

This section details the methodological steps the pilot project took to assess the credit risk impacts associated with the climate transition scenarios.

The approach to assessing credit risk combined the top-down financial impacts generated from the scenarios with the bottom-up, borrower-level, credit analysis done by the participating financial institutions.[13] The methodology can be broken down into three broad steps (**Figure 1**), described in more detail below.

**Figure 1: Credit risk assessment: key methodological steps**




**Step 1 (top-down)**: The first step was to calculate sector-level financial impacts for each geography using data generated by the climate scenarios. As described in the previous section, the financial impacts were captured by the RFPs—changes in direct emissions costs, indirect costs, capital expenditures and

[13] This methodology is developed as part of a UNEP-FI pilot to better equip the banking industry to implement the recommendations of the Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD). For more information, see UNEP-FI, Oliver Wyman and Mercer (2018) and UNEP-FI (2020).

revenues—relative to the baseline (2019 policies) scenario. The RFPs represent the main drivers of the credit risk estimated in the following steps.

**Step 2 (bottom-up)**: The second step was to translate the financial impacts of the transition scenarios at the sector and subsector (or segment) levels into credit outcomes (i.e., credit ratings, probabilities of default). In this step, the participating financial institutions conducted borrower-level assessments based on a sample of representative borrowers per sector/segment in their portfolios. Leveraging the RFPs, the scenario narratives and sector/segment sensitivities to changes in the RFPs (through a heat map tool described below), financial institutions used their own quantitative financial analysis tools, expert judgment and business knowledge to assess the potential impacts of the scenarios on the probability of default (PD) for each representative borrower. This step provided a more granular perspective for the assessment of the magnitude of risks.

**Step 3 (top-down)**: The third step was to estimate a climate transition–credit risk relationship—that is, the relationship between the financial impacts generated from the transition scenarios (Step 1) and the credit outcomes projected by the financial institutions (Step 2). This was done through a Merton-style model. The model mapped the RFPs along each transition scenario, sector/segment-geography, and the heat map sensitivities into changes in the PDs. A Frye-Jacobs relationship was then used to assess the loss given default (LGD) based on the stressed PDs. The credit risk to the rest of the portfolio, measured as expected credit losses (ECL), was then calculated based on projected PDs, LGDs and exposures at default.

## 3.1 Mapping climate scenario variables to financial impacts

### Defining the segments

Transition pathways can play out differently across industries within a given sector. For example, within the electricity sector, fossil-fuel power generation might experience a very different transition path than the one experienced by renewables. For this reason, we disaggregated some of the sectors into subsectors or segments.

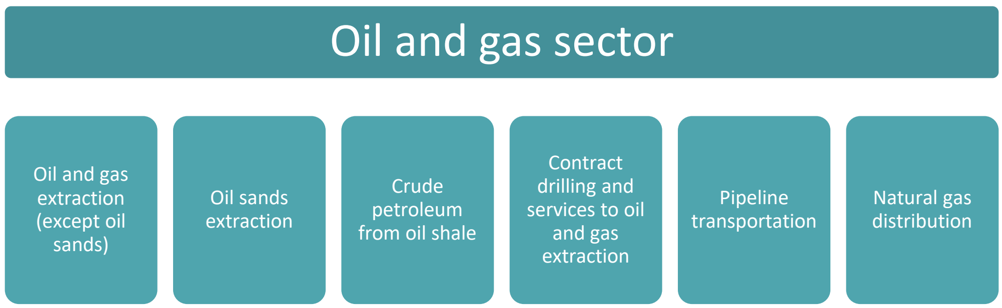
The goal was to group related industries and activities that might be similarly affected by the transition scenarios. Standard industrial classification system groupings are not designed with these considerations in mind, which implied the need to develop a new mapping scheme based on granular industrial classification codes. Given the diversity of industrial classification systems used across the financial institutions and the need to ensure consistency in the mapping of financial institutions' counterparties to the sectors selected, the Bank developed a mapping based on several industrial classification systems, including the North American Industry Classification System (NAICS) and the Global Industry Classification Standard (GICS).[14]

In the segmentation process, we needed to consider the significant heterogeneity within some sectors in terms of their exposure to the drivers of climate transition risk. To do this, we disaggregated the oil and gas, electricity, energy-intensive industries and commercial transportation sectors into segments that are largely homogeneous in terms of their exposure. For example, the electricity sector was disaggregated

[14] In defining the segments, to group more homogeneous industries together, some industries under the same 3- or 4-digit NAICS codes were bundled together. For example, pulp, paper and paperboard mills (NAICS: 3221), converted paper product manufacturing (NAICS: 3222), and printing and related support activities (NAICS: 323) were grouped as one segment as "paper manufacturing, printing and related support activities" under the energy-intensive industries sector.

into four segments. The oil and gas sector was disaggregated into six segments (**Figure 2**). The final degree of disaggregation was agreed to among the pilot participants by balancing the benefits of added granularity with their resource availabilities. The full list of segments (23 segments in total) considered in the pilot project is presented in **Table 1** (found in the next subsection) and the full mapping to NAICS and GICS can be found in the appendix of this report.

**Figure 2: Example of segments in the oil and gas sector**




## Constructing the heat map tool

A heat map tool was constructed to evaluate the financial responsiveness or sensitivities of a given segment to the sectoral RFP components. While RFPs show how the transition scenarios affect different sectors, the heat map presents how different segments are sensitive to the sectoral RFPs. Therefore, the heat map allowed the risk assessment process to include impacts at an intra-sectoral level. The tool was used to inform both financial institutions' borrower-level assessments (Step 2) and the top-down calibration phase (Step 3).

The segment sensitivities to each RFP component in the heat map were ranked according to six levels: negative, low, moderately low, moderate, moderately high and high (**Table 1**). The ranking was assessed relative to the average of a segment's associated sector. For example, if a segment's emission intensity was higher relative to its sector's average, its sensitivity to the direct emissions costs RFP component was ranked as high in the heat map. The heat map sensitivities, however, are not comparable across sectors. For instance, if a segment's response to a specific RFP component is rated as low, it does not mean this impact is similar to the impact for another low-rated segment in another sector.

The heat map tool was based on the pilot's below 2°C immediate scenario and considered an "average" view of the sensitivities of segments to the RFPs (i.e., a segment's sensitivity to a given RFP stayed the same under the other scenarios). Given this, and depending on the specific exposures of a financial institution's portfolio (e.g., these may vary across jurisdictions), it may be valuable to consider different segmentation ranking schemes.

The heat map tool was informed by data covering different segment characteristics. For instance, Statistics Canada's 2021 emissions-intensities data were used to evaluate the sensitivities of segments to the direct emissions costs RFP component (Statistics Canada 2021). To inform sensitivities for the indirect costs RFP component, we leveraged data from Statistics Canada's input-output tables to capture the importance of energy-intensive inputs (e.g., electricity, cement, iron, and steel) in a segment's supply chain (as measured by value added).[15] We used information on marginal abatement cost curves (including from McKinsey and Company 2009), which provide sectoral information on volume and cost of different options for emission reductions, to inform the assessment of sensitivities for capital expenditures. Last, we used information obtained from a variety of sources to evaluate the impacts on revenues (e.g., studies estimating the price elasticity of demand for specific segments, information on a segment's market structure, and metrics from literature based on other scenario sources).[16]

### Table 1: Sectoral segmentation and heat map tool

| Sectors | Segments | Direct emissions cost | Indirect costs | Low-carbon capital expenditures | Revenues |
|---|---|---|---|---|---|
| **1) Livestock** | 1) Livestock | Moderate[17] | | | |
| **2) Forestry** | 2) Forestry | | | | |
| **3) Crops** | 3) Crops | | | | |
| **4) Coal** | 4) Coal | | | | |
| **5) Refined oil products** | 5) Refined oil products | | | | |
| **6) Oil and gas** | 6) Oil and gas extraction (except oil sands) | Moderately high | Moderately low | Moderate | Moderate |
| | 7) Oil sands extraction | High | Moderately high | Moderately high | High |
| | 8) Crude petroleum from oil shale | Moderately high | Moderately high | Moderately high | Moderately high |
| | 9) Contract drilling and services to oil and gas extraction | Moderately low | Moderate | Moderately low | Moderately high |
| | 10) Pipeline transportation | Moderate | Moderately high | Moderate | Moderately low |
| | 11) Natural gas distribution | Low | Low | Moderately low | Moderately low |
| **7) Electricity[18]** | 12) Fossil-fuel electric power generation | Moderately high | Moderately high | Moderately high | Negative |
| | 13) Hydro and nuclear | Low | Low | Moderately low | Moderately low |
| | 14) Other renewables | Low | Moderately low | Moderately low | Moderately high |

[15] See "Supply and use tables," Statistics Canada (2018).

[16] For example, studies such as *The Growing Role of Minerals and Metals for a Low Carbon Future* by the World Bank Group (2017) provide a picture of the market structure for metals and minerals in a low-carbon economy.

[17] For sectors that have only one segment (i.e., livestock, forestry, crops, coal, and refined oil products), RFP effects for the segment are set at the sector's average. The sensitivity for these segments is thus assumed to be "moderate."

[18] Note that in contrast to other sectors, revenues increase in the electricity and commercial transportation sectors for most of the years along the transition scenarios compared with the baseline (2019 policies) scenario. Therefore, the interpretation of revenue sensitivities for the segments within these sectors is different than for the other sectors. For example, fossil-fuel electric power generation has a negative revenue sensitivity since its revenue goes the opposite direction of the sectoral revenue, while other renewables (i.e., solar and wind) and rail transportation, which benefit more than the sectoral average, are assigned a revenue sensitivity of "moderately high."

| | | | | | |
|---|---|---|---|---|---|
| | 15) Electric power transmission, control and distribution | Low | Low | Moderate | Moderate |
| **8) Energy-intensive industries** | 16) Paper manufacturing, printing and related support activities | Moderately high | Moderately low | Moderate | Moderate |
| | 17) Chemical manufacturing, plastics and rubber products manufacturing | Moderate | Moderately low | Moderately high | Moderate |
| | 18) Non-metallic mineral product manufacturing | Moderately high | Moderate | Moderately low | Moderate |
| | 19) Primary metal manufacturing and fabricated metal product manufacturing | Moderately low | High | High | Moderate |
| **9) Commercial transportation** | 20) Air transportation | High | Moderately low | High | Low |
| | 21) Rail transportation | Moderately low | Low | Moderately low | Moderately high |
| | 22) Water transportation | Moderately high | Moderately low | Moderately high | Moderate |
| | 23) Truck transportation, transit and ground passenger transportation, and other transportation (scenic and sightseeing transportation, support activities for transportation, couriers and messengers, and warehousing and storage) | Moderately low | High | Moderate | Moderate |

## 3.2. Borrower-level assessments

This subsection describes how participating financial institutions conducted the borrower-level assessments from a sample of representative borrowers selected from their portfolios. The purpose of this step is to overcome the lack of data on the relationship between climate scenarios and credit outcomes, and to avoid financial institutions from having to manually assess all of their exposures along each scenario. The assessments provided “calibration points” that were used in Step 3 (presented later) of the credit risk assessment methodology, including to estimate credit outcomes to an institution’s whole portfolio. This bottom-up phase contributed to providing more granular perspectives on the potential credit impacts (credit ratings or PDs) of the climate transition on financial institutions’ portfolios, and in this way represented a critical step for the assessment of the magnitude of risks. In addition to using their in-house expertise, financial institutions leveraged the top-down information described in the previous sections to estimate credit outcomes: namely, the sector/segment–level RFPs, the scenario narratives and the heat map tool.

### Selecting the sample of representative borrowers

Financial institutions were asked to select a sample of representative borrowers within each sector/segment and each geography from their portfolio to evaluate the changes in credit ratings associated with the financial impacts of the different climate transition scenarios. For the pilot project, financial institutions selected a minimum of five borrowers within each sector/segment and geography.[19] They were also asked to estimate credit ratings for each selected borrower for at least two time periods

[19] Analysis of five borrowers per segment enables a unique solution to the calibration formula, which contains five sensitivity parameters per segment. Details are presented below in equation 2. For more information, see UNEP-FI, Oliver Wyman and Mercer (2018).

(e.g., for years 2030 and 2040) for at least one of the two transition scenarios (e.g., below 2°C immediate and/or below 2°C delayed scenario).[20]

Given the importance of the borrower-level credit information for the credit risk assessment methodology, we draw attention to the following factors to keep in mind when selecting a sample of representative borrowers.

First, sampled borrowers should be representative of the segment or sector regarding the distribution of credit ratings/probability of default (PD), distribution of exposure/loan size and other relevant borrower characteristics. For example, it is useful when segments contain borrowers that are different in terms of their initial PD and credit exposure, as this provides a more accurate picture of the distribution of credit outcomes. Such a distribution serves to reflect not only the average of the whole segment but also its dispersion/concentration among the borrowers in that segment.

Second, other borrower characteristics, such as a company's size and the nature of its business operations, are also factors to consider in the selection process. However, some characteristics may render a borrower unfit to be representative of the segment. For example, if a borrower has announced a strategic plan to move away from its current emission-intensive production process, that borrower should not be selected for the sample if most of the borrowers in that segment have not committed to do the same.

Ultimately, efforts to identify representative borrowers and the size of the sample for each segment/geography need consider the characteristics of the firms in the financial institutions' portfolios and, pragmatically, the constraints of the institutions' resources.

### Assessing credit outcomes

Leveraging the sector-level RFPs, the scenario narratives and the heat map, the pilot participants used quantitative financial analysis of credit risk and expert judgment to assess the potential impact of the scenario on the PD for this sample of borrowers. The financial institutions relied on their in-house quantitative financial analysis tools, data and expert judgment to support their credit risk assessments. Given the starting financial statements of the borrowers, the financial institutions applied the RFPs to compute the borrower's transition-impacted financials. These financials were then translated into standard metrics of credit risk indicators, such as debt-to-EBITDA[21] ratios, which were translated into credit outcomes (credit ratings or PDs).[22]

### Guidance for assessing credit outcomes

The borrower-level calibration required significant investment and expertise by the financial institutions. Specifically, there are three aspects that make a climate risk assessment a challenging exercise. First,

[20] For this pilot, as explained in section 2, the Bank developed four global climate transition scenarios over a 30-year horizon, from 2020 to 2050. The model solves at five-year intervals up to 2100, while results up to 2050 were used for the credit risk analysis. After estimating the climate transition–credit risk relationship (in Step 3 of the analysis), we can calculate the impacts of any transition scenario on the credit outcomes using the estimated relationship. In the pilot project, the sample-specific impacts were assessed based on the two below 2°C scenarios, while the portfolio impacts in Step 3 were calculated for all three transition scenarios, including the net-zero 2050 (1.5°C) scenario.

[21] EBITDA refers to earnings before interest, taxes, depreciation and amortization.

[22] The financial institutions assessed the effects of the transition scenarios on PDs and on S&P Global credit ratings of the selected borrowers. If the institutions provided only the credit ratings, the associated PDs (obtained from the S&P mapping) were used in the estimation model in Step 3.

traditional risk assessment exercises typically cover only a two- to five-year period, while the financial impacts associated with the climate transition scenarios are spread over a much longer time horizon. In this setting, understanding how the transition pathway may play out for a given sector/segment is more complex. Second, while traditional risk assessment exercises are typically driven by macro factors, sector-specific dynamics are an important component to conduct climate transition risk assessment. Lastly, historical credit outcomes to inform the borrower-level assessments are less reliable because of the distinct features associated with climate-related risks. To overcome these challenges, the financial institutions need to make many assumptions in the projection of the borrower's transition-impacted financials over a long time horizon. To provide some consistency and comparability in the borrower-level assessments across the financial institutions, the Bank and OSFI provided guidance in some areas, including on:

- the interpretation and use of the scenario data. The financial institutions were advised to fully leverage the scenario data in their analysis and that expert judgement should not overwrite the scenario data, especially if there was a misalignment between the financial institutions' experts' views on the transition and the scenarios.
- how to account for business risks and the extent to which unannounced future borrower's plans should be considered. The financial institutions were encouraged to consider changes in business risk in their assessment. In addition, the financial institutions were advised to only consider borrowers' future operational and strategic plans that were known by the end of 2019. Finally, guidance was provided on how to treat borrowers' long-term contracts.[23]
- additional assumptions that were required for the borrower-level financial assessments, for example, on whether to assume that borrower's free cash flow was used for net debt reduction, capital expenditures or shareholder rewards. These assumptions are important because they affect the accumulation of debt and thus the assessments of credit outcomes.

Despite the guidance provided, significant variability across financial institutions' methodologies and assessments remained. This made the consistency and comparability of results particularly challenging. Section 3.5. will provide more insights on these challenges.

## 3.3. Estimating the climate transition–credit risk relationship

This subsection presents the methods in Step 3 of the credit risk assessment methodology. In this top-down step, we estimated a climate transition–credit risk relationship: that is, the relationship between the financial impacts generated from the transition scenarios (Step 1) and the credit outcomes from the sample of borrowers provided by the financial institutions (Step 2). The relationship was estimated using a Merton-style model, which mapped the RFPs along each transition scenario into changes in the related PDs for each sector/segment and geography. The estimation procedure also ensures that the segments' sensitivities are consistent with the ranking presented in the heat map. A Frye-Jacobs relationship was then used to assess the LGD based on the projected PDs. The credit risk to the rest of the financial institutions' portfolios was then estimated based on projected PDs, LGDs and exposures at default. The participating financial institutions provided the latter for their representative borrowers and their

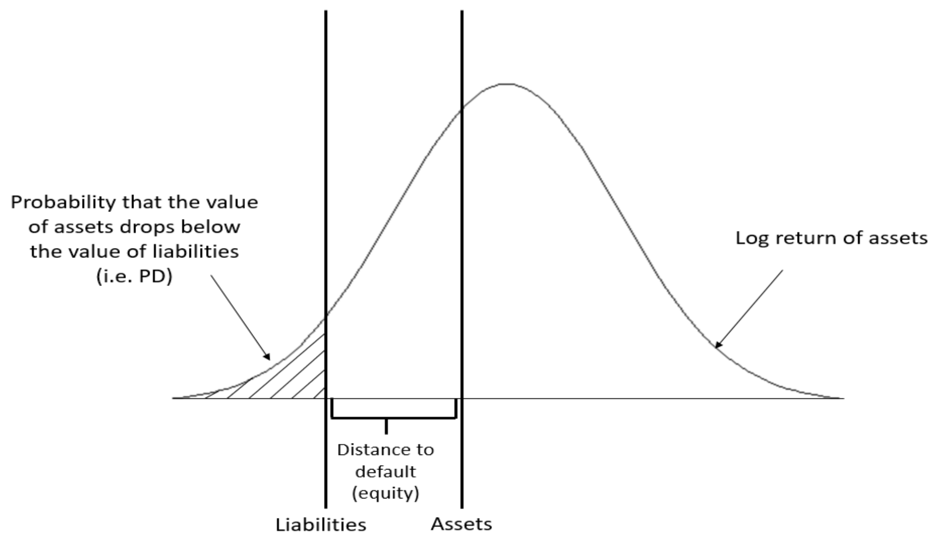
[23] For example, long-term fixed-price contracts were not to be considered beyond the term of the current contracts.

portfolio.[24] The following subsection presents a description of these tools and how they were applied in the pilot.

### Merton framework to assess credit risk

The Merton model, which was originally developed by Robert Merton in the 1970s, is often used to understand the risk of a borrower defaulting (Merton 1974). In this model, the PDs are related to the likelihood that the firm's future asset values could fall below a threshold value, specified by the value of the firm's liabilities (**Figure 3**).

**Figure 3: Definition of probability of default (PD)**




Within the Merton framework, rating transitions are assumed to be driven by a continuous, normally distributed underlying credit indicator reflecting the change in value of the firm's assets, which can be further decomposed into a systemic component and an idiosyncratic component. Climate transition risk drivers, as captured by RFPs, are introduced in the model as an additional systemic risk that shifts the firms' asset values. The shift in the distribution of asset values at a given point in time can be translated into an increase or decrease in PD, with idiosyncratic and other systemic factors remaining unchanged. The magnitude of the shift due to climate transition risk is determined by a combination of the RFPs and the sensitivities of the PDs to the RFPs. The scenario-adjusted PD of a borrower can be written as a function of its original PD and the climate credit quality index of its segment:

$$PD_{ijk}|c^* = \Phi\left[\Phi^{-1}\left(PD_{ijk,TTC}\right) - \text{climate credit quality index for segment j in sector k}\right], \qquad (1)$$

where $PD_{ijk}|c^*$ is the scenario-adjusted PD for borrower *i* in segment *j* and sector *k*, $PD_{ijk,TTC}$ is the through-the-cycle probability of default (TTC PD) or the initial PD for borrower *i*, and $\Phi$ is the standard

[24] Exposures at default in the pilot project were for December 31, 2019.

normal distribution. The climate credit quality index is defined as a function of the RFPs associated with the climate transition scenarios and the parameters that represent the sensitivity of the PDs to the RFPs:

$$PD_{ijk}|c^* = \Phi[\Phi^{-1}(PD_{ijk,TTC}) - \frac{1}{\alpha_k}\sum_r s_{jk}^r f_k^r], \qquad (2)$$

where $f_k^r$ is the risk factor *r* (i.e., changes in direct emissions costs, indirect costs, capital expenditures, and revenues relative to the baseline [2019 policies] scenario) for sector *k*, $s_{jk}^r$ is the sensitivity of segment *j* in sector *k* with respect to the RFP *r*. $\alpha_k$ is an indicator of the average magnitude of the scaling factor across the different segments and helps to normalize RFP values to be interpreted as a random variable with a standard normal distribution. Also note that all the variables and parameters in equation 2 can be geographic-specific. Subscripts for the geographies (i.e., Canada or United States) are suppressed from the equation for simplicity.

The PD calibration process consists of two stages. In the first stage of the calibration, optimal values for the $\alpha_k$ parameters are found based on the borrower-level calibration points provided by the financial institutions and the RFPs. To find the value of the $\alpha_k$ parameters, we set all the $s_{jk}^r$ as equal to one and fitted the $\alpha_k$ parameters using least squares optimization. When $\alpha_k$ becomes very large, neither sensitivities nor the RFPs will have any impact on segment risk. To prevent this, we applied an upper bound for $\alpha_k$ so that in these cases the sensitivities still play a role in PD migration.[25]

In the second stage of calibration, we find an optimal value for each sensitivity for each risk factor pathway level. After $\alpha_k$ is found, sensitivity values are used to fit PD impacts to segment-level calibration points. Sensitivities are constrained in the optimization problem in the sense that the calibrated sensitivity values should be consistent with sensitivity assessments coming from the heat map, for example, "high" sensitivities have a more adverse impact than "low" sensitivities. Sensitivity values have six levels—negative, low, moderately low, moderate, moderately high and high—based on the heat map presented in section 3.1. To prevent sensitivities from taking on extreme values and causing segment-level results to differ dramatically from underlying RFPs, we define upper and lower bounds for each of the RFP levels.

### Credit portfolio impact assessment

The credit risk assessment methodology measures the impact of the climate scenarios, relative to the baseline (2019 policies) scenario, on the PD and LGD of individual exposures. It then calculates portfolio-

[25] In the pilot project, we also considered the nonlinearity in the model to better fit the submitted migrated PDs by the financial institutions. This is because in the submitted PDs migration for some of the sectors, we observed that changes in the migrated PDs vary nonlinearly with the size of RFPs. In other words, for some sectors, changes in the submitted PDs were relatively larger when the magnitude of the RFPs becomes larger. Therefore, we took into account this nonlinearity by adding the term $\beta_k(\sum_r(s_{jk}^r f^r{}_k))^2$ to the model and estimating $PD_{ijk}|c^* = \Phi[\Phi^{-1}(PD_{ijk,TTC}) - \frac{1}{\alpha_k}(\sum_r s_{jk}^r f^r{}_k - \beta_k(\sum_r(s_{jk}^r f^r{}_k))^2)]$. In this model, $\beta_k$ captures the nonlinearity of the response of the changes in PD with respect to the RFPs. Since $\beta_k$ is also at the sector level (similar to $\alpha_k$), both $\alpha_k$ and $\beta_k$ can be estimated simultaneously as a pair in the first stage of the calibration process.

level ECLs. To calculate these, we estimate a scenario-implied PD for all borrowers in a segment based on their starting PDs, using equation 2, once all the parameters in equation 2 are calibrated. In the context of the pilot, the portfolios of the participating financial institutions were used to estimate the PDs for all borrowers in their respective portfolios for the three scenarios. Section 3.4. presents a summary of these estimated PDs (changes relative to initial PDs) by sector and geography under the three scenarios.

LGD, the second element of expected loss, can be directly estimated based on the stressed PD using the Frye-Jacobs relationship,[26] which provides a single-parameter, generic relationship between PD and LGD as follows:

$$LGD_{Transition} = \frac{\Phi\left[\Phi^{-1}(PD_{transition}) - [\Phi^{-1}(PD_{TTC}) - \Phi^{-1}(PD_{TTC} * LGD)]\right]}{PD_{transition}}, \qquad (3)$$

where $PD_{transition}$ is the estimated migrated PD under the climate scenario in a given year, $PD_{TTC}$ is the initial TTC PD, and $LGD$ is the initial LGD. The ECL of an individual exposure $i$ is then calculated as the product of exposure at default (EAD), LGD and the probability of default (PD). The ECL of a portfolio, $P$, is calculated as the sum of the ECL of the $n$ individual exposures.

$$ECL_P = \sum_{i=1}^{n} EAD_i \cdot PD_i \cdot LGD_i \qquad (4)$$

## 3.4. Illustrating the credit risk methodology

This subsection discusses the climate transition–credit risk relationship that was estimated by applying the above tools and methods. Specifically, the estimated relationship is between:

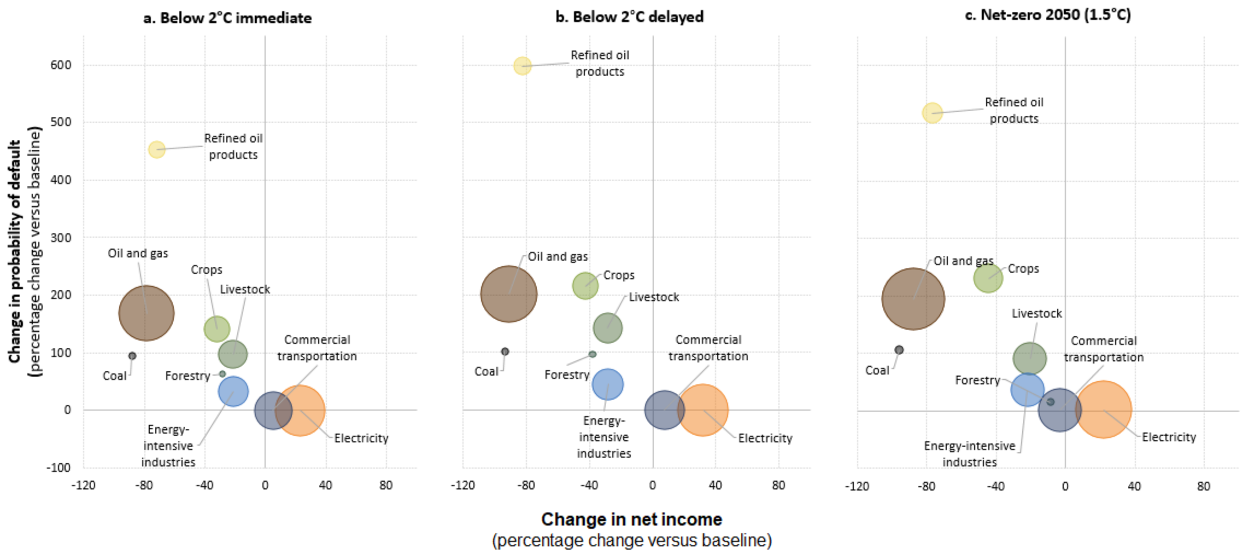
- the financial impacts driven by the climate transition in each sector, measured as the percentage change in net income by 2050 relative to the baseline (2019 policies) scenario, and
- the exposure-weighted average percentage change in PD for each sector, measured as the percentage change in PDs for each sector by 2050 relative to the baseline (as estimated by the credit model).

**Chart 4** illustrates this relationship.[27] The size of a bubble in the chart is proportional to the total exposure for a sector (in December 2019). The chart illustrates an overall negative relationship between the magnitude of the financial impacts for a sector and the scale of the change in credit risk generated from the borrower-level assessments. Borrowers in sectors that are more negatively affected by the transition scenarios are projected to have larger percentage increases in their PDs. Also, for more costly transition scenarios, such as in the below 2°C delayed action scenario, the credit risks are generally larger.

[26] For a description of the methodology, see Frye and Jacobs (2012).

[27] Chart 4 is based on the combined borrower samples of the pilot participants, showing this relationship for Canadian sectors. See Bank of Canada and OSFI (2022) for details and a discussion on the credit risk results.

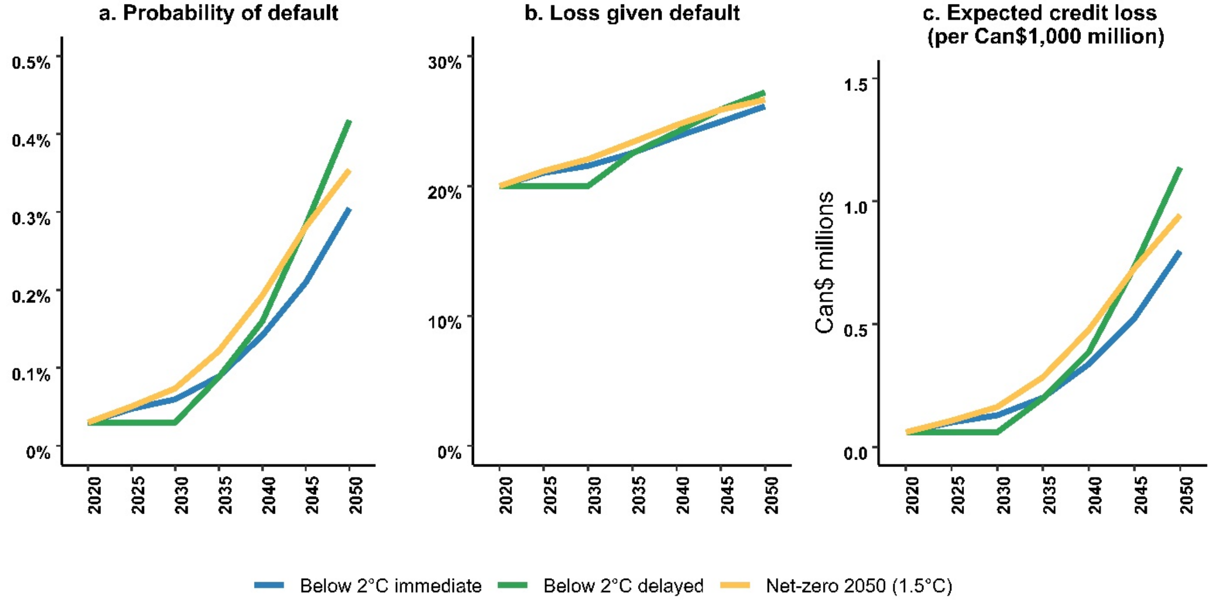
**Chart 4: Climate transition–credit risk relationship - Canada 2050**




**Source: Bank of Canada and OSFI (2022)**

For any hypothetical borrower, given the initial PD (associated with the initial credit rating), the segment and geography, the migrated PD in each year can be projected under each of the scenarios using the Merton-style model estimated based on the borrower-level assessments. In addition, given initial PD, initial LGD and the projected PDs, the LGD is calculated in each year based on the Frye-Jacobs relationship outlined in equation 3 above. Multiplying PD by LGD and the exposures gives ECL values. These estimates are based on the combined borrower samples of the six pilot participants. **Chart 5** shows the estimated PD, LGD and ECL for a hypothetical representative borrower in the petroleum and coal products manufacturing segment (i.e., refined oil products sector) in Canada with a given initial credit rating of AA- and initial LGD of 20 percent (at the end of 2019).

**Chart 5: Estimated credit outcomes of a hypothetical borrower in Canada's petroleum and coal products manufacturing segment**




**Source: Bank of Canada and OSFI (2022)**

## 3.5. Methodological lessons learned and limitations

Overall, the bottom-up credit risk assessment method used in combination with the top-down climate scenario analysis enabled pilot participants to develop a deeper understanding and awareness of the impacts of the climate transition on their portfolios. The analytical framework also helped them to identify the related data gaps needed to conduct borrower-level climate-related financial risk assessment. However, the framework revealed some limitations and challenges.

The discussion around the importance of ensuring the representativeness of the borrowers in an institution's portfolio sample showed that this was a critical step in the credit risk assessment process: namely, by drawing attention to some complex considerations in borrower selection. These included being mindful that the sampled borrowers should be representative of the segment or sector regarding the distribution of credit ratings/probability of default (PD), distribution of exposure/loan size and other relevant borrower characteristics. The discussion also highlighted the need to account for institutions' own resource constraints in conducting their assessments, including in consideration of the benefits of increasing the sample size.

While the bottom-up component of the credit risk assessment provided authorities with a means to address some of the data gaps—namely, by using financial institutions' borrower-level expertise—many highlighted the lack of sufficient data (e.g., emissions data).[28] This pointed to the value of disclosures to make transition risk assessment more readily accessible at the borrower level. Such disclosures would also

[28] This was particularly salient for operations outside developed markets and for public asset classes.

enable more consistency in and comparability of how each borrower performs along the different climate scenarios. Guidance on how to map borrowers to sectors, the criteria for selecting representative borrowers and the interpretation of the scenario data in face of expert judgment were also key in guiding institutions in using information from top-down climate scenarios. The exercise showed, however, that some approaches and assumptions made across institutions prevented consistency and comparability across institutions' assessments.[29] The variability could be explained by several factors, including the following:

- **Challenges in the classification of companies and differences in the portfolios of the financial institutions**. Many participants noted that classifying companies that have multiple or mixed business lines represented a challenge (e.g., some power generation borrowers may have exposure to a variety of fuel sources). This was particularly true in the energy sector, where many companies are diversified. Differences in the classification of these companies could partly explain the variability in assessments across institutions: for example, a company that has multiple business lines where some activities are not very exposed to transition risks while others are. If this company is classified as part of a high transition risk sector/segment, credit risk of that sector/segment may be underestimated. As mentioned above, to help the participating financial institutions with these challenges, we constructed a mapping tool using standard industrial classification systems (see **Table A-1** in the appendix).
- **Differences in analytical tools, capacity, expert judgment and assumptions across institutions**. The assumptions used by the financial institutions through their borrower-level assessments could have significant implications for the results across the institutions. The differences in assumptions can be magnified by the long time horizon of the analysis and the need for additional financial assumptions (e.g., the extent to which borrowers use free cash flow to repay debt along the transition, assumptions about borrowers' future management actions, and business and counterparty risks). The exercise also showed that the use of expert judgment along the transition scenarios, including prospects of sectors, could lead to misalignment with the assumptions in the scenarios themselves (e.g., for elasticities and cost pass-through). In this light, financial institutions were encouraged to consider their expert judgment as information that could complement the narratives of the transition scenarios.

# 4. Approach to assessing climate-related market risk

This section describes the methodology used to estimate the impact of changes in climate policy on the valuation of equity securities. The approach was purely top-down, differing from the credit risk assessment approach described above, which used both top-down and bottom-up inputs. This avoided some of the challenges associated with bottom-up analysis but resulted in less granular output. The equity valuation impacts were estimated at the geography-sector level using a dividend discount model and then applied to equity portfolio holdings. The following subsections describe the model and assumptions used and discuss the methodological lessons learned and limitations.

## 4.1. Dividend discount model

Equity values under each transition scenario were estimated for Canada and the United States for each sector from 2020 to 2050 at five-year intervals using a dividend discount model (equation 5), where $Div_{t,i}$

[29] Notably, the pilot project results showed there was considerable variability across financial institutions when comparing the climate transition–credit risk relationships.

is the dividend from sector $i$ at time $t$, $RF$ is an estimated risk-free rate and $ERP$ is an estimated equity risk premium.

$$Equity\ value_{i,t} = \sum_{s=1}^{50} \frac{Div_{i,t+s}}{(1+RF+ERP)^s} \qquad (5)$$

Because the sectoral dividend flows were not directly observable from the sectoral variables generated from the scenario development component of the pilot, the sectoral dividends under each transition scenario were calculated from projected value added, along with assumptions on capital share of value added and a dividend distribution rate. We assumed a capital share of value added equal to one-third and a fixed dividend payout ratio of 50 percent (equation 6).[30] Sectoral value added was calculated as the difference between the revenue and cost-related RFPs (direct emissions costs, indirect costs and capital expenditures) described in section 2. The use of the RFPs in this way created a direct link between the bottom-up credit analysis and top-down market risk analysis.

$$Div_{i,t} = value\ added_{i,t} \cdot capital\ share \cdot div\ payout\ ratio \qquad (6)$$

The estimated, geography-specific sectoral dividend streams were then discounted using the historical average return from the Morgan Stanley Capital International World Index from April 1, 1970, to December 31, 2019, equal to 7.87 percent.

## 4.2. Foresight assumptions

Geography-sector equity index values were estimated by discounting computed annual dividend flows within a 50-year, forward-looking window for each of the three climate transition scenarios from 2020 to 2050. This required estimating sectoral dividends from 2020 to 2100. Since expected future dividend flows were used to estimate the value of equity, assumptions were needed about the foresight of economic agents for the net-zero 2050 (1.5°C), below 2˚C immediate and below 2˚C delayed scenarios.

For the net-zero 2050 (1.5°C) and below 2°C immediate scenarios, we assumed economic agents had 10-year foresight of the impact of climate policy on dividends starting in 2020. For the below 2°C delayed scenario, we assumed that economic agents expected dividend flows to follow the baseline (2019 policies) path until 2030, when climate policy shifted unexpectedly to the below 2°C delayed path. We assumed economic agents incorporated the expected dividend flows from the below 2°C delayed path with 10-year foresight in and after 2030.

## 4.3. Geography-sector equity valuation

Once equity values were estimated for each geography-sector under the baseline (2019 policies) scenario, net-zero 2050 (1.5˚C), below 2˚C immediate and below 2˚C delayed scenarios, we computed equity indexes for each sector. The objective of the indexes was to measure changes in valuation caused by changes to climate policy only, not the dynamics of the baseline (2019 policies) scenario. Therefore, the sectoral equity indexes were computed as the ratio of scenario equity valuations relative to baseline each

[30] These assumptions are similar to the ones made in the ACPR (Autorité de Contrôle Prudentiel et de Résolution) Pilot Climate Exercise (see ACPR 2020).

year. Equation 7 shows the equity index calculation at time *t* for scenario *i*. Equity indexes were computed at five-year intervals across the three scenarios for each geography-sector.

$$Equity\ index_{t,i} = \left(\frac{equity\ value_{t,i}}{equity\ value_{t,baseline}}\right) \qquad (7)$$

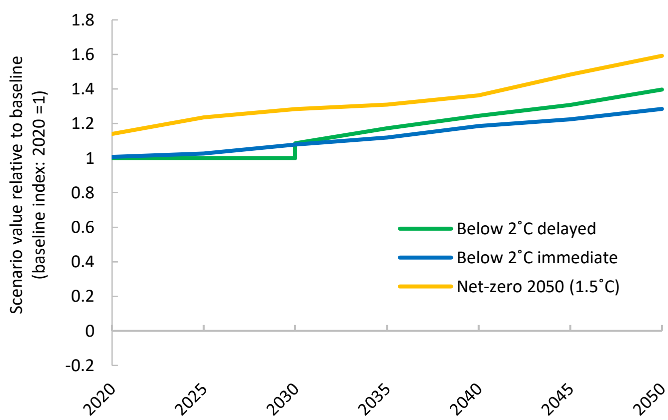
## 4.4. Determining equity exposures in scope

Equity valuation indexes were computed across all sectors in Canada and the United States.[31] Both public and private equity exposures were in scope for the exercise and were treated equally.

## 4.5. Illustrating the market risk methodology

**Chart 6** shows valuation impacts on the Canadian electricity sector[32] following a shift in global climate policy relative to the baseline (2019 policies) scenario. The same discount rate, capital share and dividend distribution rate were assumed across all sectors and geographies. Therefore, sectoral value added and assumptions around investor foresight were the main drivers of equity market valuation differences across scenarios, sectors and geographies.

**Chart 6: Canada electricty sector equity valuation**




**Source: Bank of Canada and OSFI (2022)**

In the below 2˚C delayed scenario, the sudden change in global climate policy path in 2030 causes an abrupt adjustment to asset values as economic agents begin incorporating carbon price information from the new policy path. In the below 2˚C immediate and net-zero 2050 (1.5°C) scenarios, a smoother adjustment happens as the change in global policy path in 2020 gets priced in.

[31] For the purposes of the pilot, equity exposures from outside of Canada and the United States were either mapped to Canada or the United States or excluded from scope.

[32] A complete set of the market risk results can be found in Bank of Canada and OSFI (2022).

### 4.6. Methodological lessons learned and limitations

Although the top-down market risk methodology was less resource-intensive and enabled consistent application across financial institutions, the relative simplicity of the approach had drawbacks that should be acknowledged by future users.

Since the RFPs used to estimate dividend flows were computed at the sectoral level, they were unable to measure intra-sector equity valuation impacts. This implied, for example, that equity exposures from oil sands extraction and natural gas distribution have the same estimated valuation impacts. Future use of this market risk methodology could benefit from adding greater sectoral granularity.

The analysis also assumed that changes in global climate policy were permanent and credible and that economic agents possessed 10-year foresight. In reality, the path of global climate policy and the timing of policy changes are highly uncertain and may not be fully priced into equity valuations. This implies that equities might be subject to frequent revaluations as new information becomes available.

Additionally, the dividend discount model used to support the market risk methodology relies on the assumption of a fixed equity risk premium, which does not capture the differences in expected return of private versus public equity. It estimates the intrinsic value of equities, which can deviate significantly from actual market valuations. The challenges and assumptions of the market risk methodology discussed here are typical of a forward-looking model but should be understood and acknowledged by users.

## 5. Summary remarks

The pilot project represented an important foundational step to help strengthen our understanding of the economic and financial system implications associated with a transition to a low-carbon economy. This report provided details related to implementing the financial risk assessment methodologies used in the Bank and OSFI pilot to assess climate-related financial risks using the information generated from the climate transition scenarios.

The report provided guidance and discussion on the implementation of the methods. In sharing the details of the methodological approaches, the Bank aims to support the broader community of financial sector participants in building their capabilities in climate-related financial risk assessment. Our hope is that this information, along with the published data on the climate transition scenarios, supports the financial sector's own efforts to assess and disclose climate-related transition risk. Ultimately, this will enable better understanding and awareness of the Canadian financial system's exposures to climate-related risks and improve associated risk management capacities.

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# 7. Appendix

Table A-1: Mapping exposures to sectors using NAICS and GICS industrial classification systems

| Sector | NAICS | GICS |
|---|---|---|
| **LIVE** | 112 | 30202010, 30202030 |
| **FORS** | 113 | 15105010 |
| **CROP** | 111 | 30202010, 15105010 |
| **COAL** | 2121, 213117, 213119 | 10102050, 15104050, 15104020 |
| **OIL** | 213111, 213118, 2111 | 10102010, 10102020, 15104020, 10101010, 10101020 |
| **GAS** | 2212, 213111, 213118, 2111 | 551020, 10102010, 551050, 551030, 10102020, 15104020, 10101010, 10101020 |
| **ELEC** | 2211 | 551010, 551050, 551030, 55105020 |
| HYDRO | 221111 | 55105020 |
| NUCLEAR | 221113 | 551010, 551050, 551030 |
| FOSSIL FUELS | 221112 | 551010, 551050, 551030 |
| OTHER (i.e., geothermal, solar, tidal, wind) | 221119 | 551050 |
| **TRAN** | 488, 492, 481, 493, 483, 487, 486, 482, 485, 484 | 201010, 203020, 20305010, 20201070, 20305020, 25301020, 10102010, 25301030, 203030, 20305030, 551030, 10102040, 20304010, 20304020, 203010 |
| **EINT** | 322, 323, 325, 326, 327, 331, 332 | 151020, 45103010, 201010, 201020, 201030, 303010, 303020, 352010, 352020, 15101010, 15101020, 15101030, 15101040, 15101050, 15103010, 15103020, 351030, 15105020, 15104010, 15104020, 50202020, 15104025, 15104030, 15104045, 15104050, 50202010, 20104010, 20106020, 20201010, 20201060, 25101010, 25101020, 25201020, 25201030, 25201040, 25201050, 252020, 25302020, 35101020, 50201040, 45103020 |
| **FOOD** | 311, 312 | 30202010, 30201010, 30201020, 15101020, 30101030, 30202030, 30201030, 15101050, 302030 |
| **ROIL** | 324 | 10102050, 15101010, 151020, 15101020, 10102010, 10102030 |
| **OTHR** | 339, 334, 336, 333, 2122, 2123, 314, 315, 316, 335, 321, 238, 236, 237, 2213, 337, 313, 213117, 213119 | 50201010, 201010, 20106015, 15104010, 25203010, 25101010, 25102010, 201020, 25301010, 10102050, 452010, 201030, 20106010, 151020, 25201010, 15104025, 15101020, 15104020, 20104010, |

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| | | 45203015, 45203010, 45203020, 20201050, 15101030, 25203020, 15105010, 15104030, 35101010, 35102015, 35101020, 20104020, 20305020, 25201020, 25201030, 25201040, 303010, 25201050, 20106020, 352030, 15103010, 25102020, 50202010, 551030, 20201060, 10101020, 15103020, 303020, 15104040, 50201040, 60102030, 45301010, 45301020, 15104045, 25302020, 15104050, 452020, 25203030, 551040, 60102010, 252020 |
| **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 | 50201010, 201010, 30202010, 203010, 20305010, 50101010, 25504010, 45103010, 40203010, 25504050, 50201020, 50201030, 25301010, 20201010, 25504020, 201030, 402020, 45102020, 25503010, 40101010, 40203030, 15104020, 60102010, 60101010, 20201070, 30101010, 25302010, 20201050, 40203040, 30101020, 30101030, 15105010, 25503020, 15104030, 35102010, 35102020, 60101050, 35102015, 351030, 25504030, 25504060, 60101030, 25301020, 20202010, 30101040, 60101020, 40301010, 10102010, 50101020, 502030, 255020, 45102030, 40203020, 45102010, 25301030, 40301020, 352030, 35102030, 40204010, 50202010, 40301030, 40201030, 60101040, 20201060, 10101020, 10102030, 10102040, 40201020, 30202030, 15104040, 40301040, 50201040, 20304010, 60102030, 60102020, 60102040, 40101015, 40301050, 20202020, 60101060, 25301040, 60101070, 20201080, 15104045, 25302020, 40201040, 60101080, 25504040, 15104050, 45203030, 401020, 201070, 20304020, 50102010, 255010, 201050 |

**Source: Bank of Canada and OSFI (2022)**