INTEGRATING CLIMATE RISK INTO CREDIT RISK MODELLING

Climate change is a growing threat to all the financial system and is already considered as a source of financial risk and then as risk drivers of traditional risk categories. In practice, credit risk will be one of the classical risk categories strongly impacted by transition and physical risk drivers. Indeed, it will probably lead to multiples impacts on borrowers' cash flows, capital and collateral leading to a change in their financial health and thus in their creditworthiness.

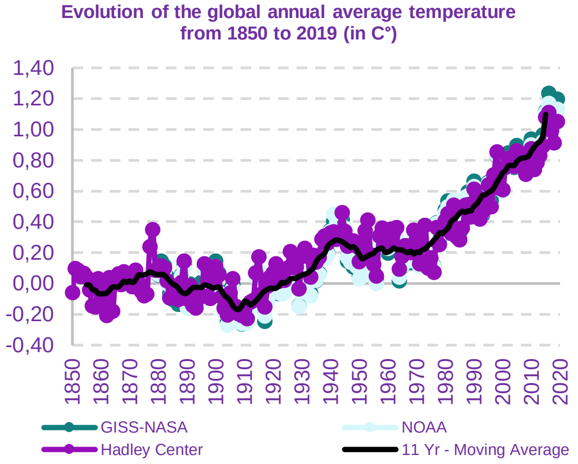
Thanks to the current efforts of working and supervisory groups but also pilot programs among the banking industry, a number of approaches to quantify the impacts of climate-related risks on credit risk are under development. Due to the methodological challenges to quantify climate-related risks and to the diversity between the different climate change pathways, expert judgment will be highly demanded when adapting the traditional credit risk models.

This opinion paper note intends to describe the emerging practices in terms of integrating climate risk into credit risk modelling.

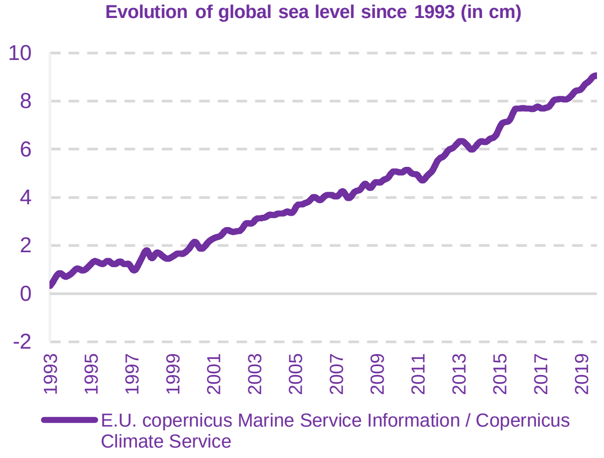
1. INTRODUCTION

Climate change is one of the major challenges of the upcoming decades. Recent years have been marked by a raising public awareness of global warming as scientists have been sounding bells about current and future consequences. Several indicators, such as the increase in global temperature, the rise of sea level, melting ice in Polar Regions and the increase of the frequency and severity of natural disasters highlight the potential devastating effects of climate change on the planet.

Temperatures are now at least 1.1°C above pre-industrial levels



Global sea average level has risen 9cm between 1993 and 2019



***Data source:** "Chiffres clés du climat - France, Europe et Monde", Edition 2021, Service de la donnée et des études statistiques (SDES).*

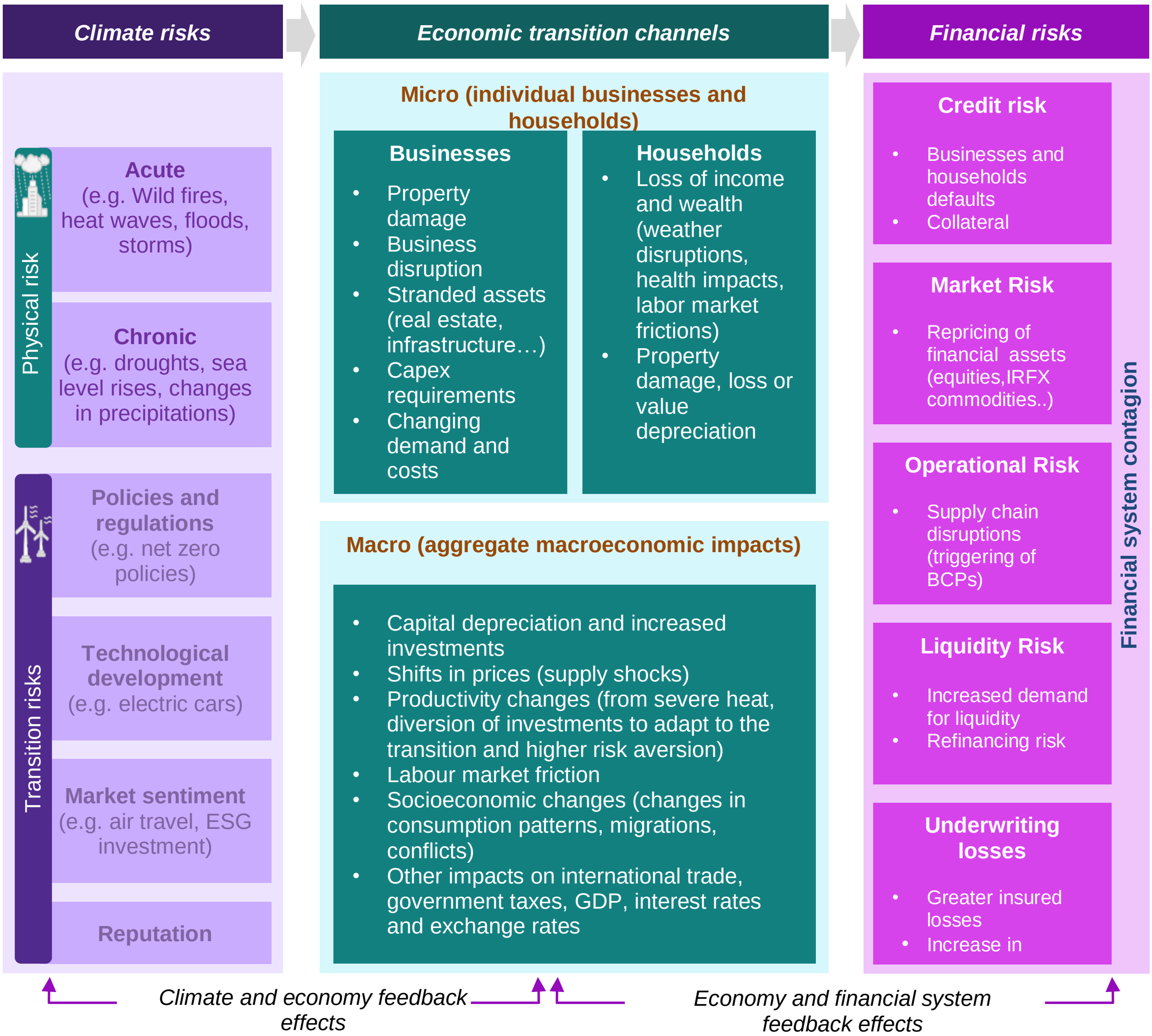
Given the urgency and the growing impacts of the climate change issue, many industries are potentially highly exposed to physical or transition risks, and from time to time to both. In particular, a number of industry sectors may have activities, products and services that may be exposed to carbon risk and are expected to experience structural shifts in their business model. Some have already engaged their transformation to a greener strategy such as the automotive sector where most major players have already introduced hybrid and electric vehicles to their catalogue.

The **banking sector**, acting as the primary driver of the global economy, is thus at the forefront of these structural changes. To resist to the consequences of global warming, banks must take the lead, integrate climate change into their **risk management framework** and adapt their systems and reporting to cope with the increasing **demands of banking supervisors**. Indeed, these last years have seen several initiatives and efforts from the regulatory and supervisory bodies such as:

- The establishment in 2015 by the Financial Stability Board (FSB) of the **Task Force on Climate-related Financial Disclosures** (TCFD) to help identify the information needed by investors and financial institutions to appropriately assess and price climate-related risks and opportunities;
- The establishment in 2017 of the **Network of Central Banks and Supervisors for Greening the Financial System** (NGFS) to share best practices and contribute to the development of environment and climate risk management in the financial sector;
- Since 2019, an increase in the initiatives carried out by the various supervisors (PRA, BCE) who **offer guidelines on how to manage climate risks** or from banking authorities (e.g. EBA) **with the launching of its action plan on sustainable finance with a 2025 timeline**

The banking sector is exposed to climate change through **macro- and microeconomic transmission channels** that arise from two distinct types of climate risk drivers. First, they may suffer from the economic costs and financial losses resulting from the increasing severity and frequency of **physical climate risk drivers**. Second, as economies seek to reduce carbon dioxide emissions, which make up the vast majority of greenhouse gas (GHG) emissions, these efforts generate **transition risk drivers**. These arise through changes in government policies, technological developments, or investor and consumer sentiment. They may also generate significant costs and losses for banks and the banking system.

The transmission channels of climate change on the economy and the financial system.



While the impact of climate risk drivers on banks can be observed through most of traditional risk categories (credit risk, market risk, liquidity risk, operational risk and reputational risk), this paper focuses exclusively on the link between **climate-related risks** and **credit risk**. It is however worthwhile noting that climate risks can also be taken as a separate / new risk category to banks, although there is currently very few literature on this approach.

Section 2 of this note illustrates how climate risks are direct drivers of credit risk, section 3 presents market practices regarding climate risk modelling within credit risk in the banking industry, while section 4 introduces the main challenges banks may face to integrate climate-related risks on their credit risk management framework.

2. CLIMATE-RELATED RISK AS A RISK DRIVER OF CREDIT RISK

As a brief reminder, credit risks are assessed based on the borrower's overall ability to repay a loan in a timely manner and according to its original terms. Three dimensions play a key role in **determining credit risk**: the borrowers' **capacity** to generate enough income to service and repay its debt, its **capital**, as well as the **collateral** available to back the loan.

1. The first dimension depends on the **borrower's cash flows**. Financial institutions review the company's past cash flow statements to determine how much income is expected from operations. This takes into account several elements such as the borrower's level of profitability, the management of its working capital, or its financial capacity to manage operations and growth.
2. The second dimension depends on the **borrowers' financial wealth**, it consists in assessing the financial structure of the business, the weight of its equity, as well as its ability to raise additional equity, if required.
3. The third dimensions depends on the **type and value of the collateral**.

Although credit risk is inherent in lending, taking into account all material risk drivers is necessary as an incomplete assessment would result in an understatement of credit risk and its related losses. Climate-related risks are becoming **material risk drivers as they affect all three dimensions** described above and may thus lead to both higher probabilities of default (PDs) and higher loss given defaults (LGDs). Having in mind these potential repercussions of climate change on the creditworthiness of borrowers, whether they are companies or individuals, the question that naturally arises is **how financial institutions can integrate these climate risks into their credit risk modeling.**

The table hereafter describes the impacts of both transition and physical climate related risks **on the three dimensions presented above, i.e. cash flows, capital and collateral:**

	Transition risks	Physical risks
On firms' cash flows	Transition risks can also affect cash flows in several ways, including, for example: - **R&D expenditures** in new and alternative technologies. - **Costs** to adopt and deploy new practices and processes. - **Reduced demand** for carbon-intensive products and services. - **Increased production costs** due to changing input prices (e.g. for energy and water) and output requirements (e.g. for carbon emissions and waste treatment).	Physical risks can have a negative impact through several channels such as: - **Reduced revenue** from decreased production capacity (e.g. due to supply chain interruptions and worker absenteeism) and lower sales (e.g. due to demand shocks and transport difficulties), - **Increased operating costs** (e.g. due to the need to source inputs from alternative more expensive supplies) and **increased capital costs** (e.g. due to damage to facilities).
On capital and collateral	The transition to a low-carbon economy can also significantly affect the value of households' and firms' assets through: - **Potential re-pricing** of stranded fossil fuel assets - **Changes in real estate valuation** (e.g. due to stricter energy efficiency standards).	Physical risks can reduce the value of households' and firms' assets both through: - **Direct damages** on assets (e.g. to houses and factories during extreme weather events) - **Write-offs** of assets situated in high-risk locations.

The tools and methodologies to assess the credit risk impact of climate change are **at an early stage of development**. However, the actual market's practices are framed **on the common following building blocks in a three steps approach such as described below:**

Block 1 Defining climate scenarios	Block 2 Estimating economic and financial impacts	Block 3 Translating financial impacts into credit risk measures
Define the set of physical climate change scenarios and the measures that will be taken to manage the transition to a low-carbon economy. These scenarios will be used to estimate the impact of climate change on credit risk through variables that are relevant for the economic activities of the borrower.	The impacts of climate change on the variables relevant for the economic activities are then required to be translated into economic terms. This requires to identify the economic agents (e.g. firms and households) that will be affected by the climate change scenarios, to then assess the direct and indirect economic impacts. At the end, these impacts will be reflected on the borrower's cash flows and balance sheets.	Once the assessment of financial impacts on the economic agents is finished, it is then necessary to compute how changes in cash flows and balance sheets will affect borrower's creditworthiness. This can be measured in terms of the probability of default (PD), the loss given default (LGD) and the credit ratings.

When implementing this approach, banks have to overcome to the **following five key methodological challenges**:

Limitations of Historical Data	**Lack of historical data to assess the impact of climate change on credit risk losses.** Past data is a poor predictor of future evolutions of physical risks. Similarly, no long-term transition policy experiments have been tested or observed. As a result, methodologies to evaluate climate-related risks rely heavily **on expert judgement**, **on specific economic variables** (e.g. assets' write-off, change in firms' costs) **and on scenarios** that estimate the impact of different GHG pathways and **the associated mitigation measures** on temperatures or other physical indicators (e.g. sea level rise).
Expanding the horizon of credit risk models	**Long-time horizons for climate-related risks challenge the way banks usually manage risks.** Assessing climate risks requires to extend the traditional horizon of credit risk analysis. Physical and transition risks may not materialize over the traditional analysis horizon of one to three years. Climate change impacts will be likely experienced **over intergenerational time horizons (over 30 to 100 years)** and the transition to a low-carbon economy will not be a short-term exercise. Then, an adequate assessment of climate risk should go beyond the short-term and extend the analysis to a horizon of at least 15 years.
Finding the right level of data granularity	**Access to firm and household-level data is limited.** Firms and households are differently affected by physical and transition risks. Physical risks depend on the **geographical location of firm's factories or household's physical assets**, while transition risks depend on the ability of firm's business models and household's income **to align with the transition to a low-carbon economy**. As a result, the assessment of climate credit risk must **be ideally based on firm and household-level data.** Unfortunately, climate risks are **generally assessed at industry and regional levels**. Transition risk assessment do not consider winners and losers within a specific sector (e.g. early producers of low-carbon electric vehicles), while physical risk estimations do not generally reflect the different degrees of resilience of assets within a specific region (e.g. various degrees of resilience to hurricanes in buildings). Granular data remains a challenge as there is **a trade-off to gauge between model's accuracy and the costs associated to obtain the data.** Consequently, some methodological approaches rely on granular data for a sample of firms and households within a specific sector or geography, **that is then extrapolated** at an aggregate, economic-wide level.
Identifying the relevant climate risk exposure metric	**Providers of climate risk analytics may integrate further metrics into their methodologies.** There is a wide number of metrics to assess climate risk. For transition risks, **current carbon emissions give an insight** of the exposure to climate risk but do not reveal how firms and households will reduce their emissions, neither reflect their level of preparedness to adapt to the low-carbon economy. These emissions are usually assessed through carbon footprints considering Scope 1 and Scope 2 emissions (the firm's direct emissions and the emissions for the energy it uses, respectively), excluding the emissions of the entire value chain and Scope 3 emissions (including the emissions of suppliers and customers). Regarding physical risks, the location of firm's manufactories and household assets give an initial insight of the exposure but do not provide information on the resilience of those assets to climate change. To tackle this problem, providers of climate risk analytics have started to integrate additional metrics into their methodologies such as firm's climate change investment strategies or green technology patents.
Translating economic impact into financial risk metrics	**Estimating financial data resulting from the economic costs of climate change.** Another challenge is to translate the economic impacts of climate change into concrete credit risk measures such as PD, LGD, or credit ratings. To do this, banks need to estimate the financial consequences (e.g. changes in client's cash flows or in collateral asset values) resulting from the economic costs of climate change. Once the financial impact is estimated, traditional credit assessment tools can be used to measure changes in credit risk.

3. MARKET PRACTICES REGARDING CREDIT RISK MODELING

During the last two decades banks have improved considerably their risk management framework, developing a variety of methodologies and tools to quantify and manage the principal risks they are exposed to. Integrating climate risk into credit risk management requires banks to adapt the actual tools for credit risk modelling. The methodologies should be based on forward-looking scenarios and longer-term modelling horizons, on complex cause and effect linkages and on data that has not observed in the past.

Even though transitional and physical risks are linked, as the former determines the magnitude of the latter, the approaches to assess the credit risk impacts are different. These methodological approaches are at the initial phase of development in the banking industry but are going at a fast pace. This section describes **some of the actual methodologies to assess the credit risks associated with the transition to a low-carbon economy and with the physical effects of climate change.** In particular, the approach framed through three key steps described before is more detailed in this section.

3.1 TRANSITION RISKS INTO CREDIT RISK MODELLING

The main objective to integrate transition risk drivers into credit risk modelling methodology is to **estimate the effects of low-carbon policies, consumer's preferences changes, and technological transitions on the banks' credit risk exposure** notably regarding asset quality and portfolio concentration composition as well as on their strategic planning and global risk profile.

3.1.1 Block – 1: Transition risk scenarios. Transition scenarios are used by researchers, policymakers and corporations to describe explore the different possible low-carbon transitions by describing changes in socio-economic systems that are compatible with achieving a climate target. Scenarios are the result of integrated energy-economy-climate models developed by the scientific community that define forward-looking pathways towards a low-carbon transition, describing plausible hypothetical interactions across time between energy use, production technologies, policies, economic sectors, geographies and sociodemographic factors. To identify the most useful scenario sources for financial assessments of transition risk, the transition scenarios must notably integrate the following considerations:

- **The level of ambition in terms of emission reduction and limiting global warming:** Widely global goals include an increase in global temperatures of 1.5°C (IPCC[1] 2018) or of 2.0°C (Paris Agreement 2015), while some others are in line with individual's reduction pledges as defined in the Paris Agreement or according to individual countries' emission reduction targets.
- **The speed of the transition:** Despite the fact that the level of cumulative emission reductions may be identical for two transition paths, the transition risk is lower when the transition path is early and smooth, in comparison to a late and sudden transition strategy.
- **The key drivers of the transition:** The following three drivers may be usually considered:
  - **Policy change:** Policy measures such as higher carbon prices, limits on emissions, subsidies for low-carbon technologies or bans for certain products and technologies.

[1] According to the studies from the Intergovernmental Panel on Climate Change (IPCC).

- **Technological change:** Low-carbon technologies' demand and/or write-offs of carbon-intensive technologies.
- **Preference change:** Reduced demand and market prices due to shifts in consumer preferences towards low-carbon products and services.

3.1.2 Block – 2: Estimating economic and financial impacts. Climate change transition scenarios are mainly developed for macro prudential policy or research purposes rather than to estimate the economic impacts on debtor's creditworthiness. Consequently, transition scenarios outputs need to be financially interpreted. It is first convenient to define the geographies, sectors or segments within sectors relevant for the bank's exposures, to then identify the risk factors that will drive the creditworthiness of borrowers over time (risk factor pathways). The main drivers of **borrower's cash flows and creditworthiness arising from transition risks** are described below:

- **Direct emissions cost** resulting from higher costs for CO2 and other greenhouse gases emissions. These costs depend on the amount of the firm's emissions and the associated carbon-equivalent price (e.g. direct tax on emitters or regulations to limit the level of emissions of industrial activities).
- **Indirect emissions cost** resulting from the supply chain. During a low-carbon transition, carbon-intensive fuels will increase in price due to pass-through of direct emissions costs. Therefore, higher carbon prices will induce indirect costs associated with increases in intermediate goods costs by firm's suppliers.
- **Capital expenditures** resulting from the costs associated with the required investments to reduce emissions and to adapt the production processes, the products and services to stricter low-carbon standards. The magnitude of these costs will depend on the price of those technologies and on the firm's capital costs.
- **Changes in revenues** resulting from changes in prices and consumer demand. The higher carbon prices on emissions is expected to be passed on to consumers. Consequently, the impact on the firm's margin will depend on the extent to which firms can pass the transition costs to their clients. Consumers, in turn, will respond to the price increase by modifying their demand. The higher the price elasticity of demand, the higher the negative impact on the firm's revenues is expected to be. In addition, other negative impacts on firm's revenues will occur for some economic activities that will not be profitable anymore, expanding the notion of "stranded assets" to "stranded business plans". To sum up, important components for estimating changes in firm's revenues are the effects of the price elasticity on sales and the sustainability of the firms' business model and product or services offer to the transition.

3.1.3 Block – 3: Translating financial impacts into credit risk measures. The risk factor pathways of the transition to low-carbon economy impact borrowers' cash flows and consequently, their capacity to service their financial obligations. In consequence, it is necessary to determine the magnitude of **the impact of the climate transition risk scenarios on the borrowers' future cash flows, to then translate these results into credit risk measures.**

In this context, the Expected loss (EL) is a key metric to consider as it estimates the amount of money that a bank expects to loss over a specific period of time. It is calculated as the product of its three determining components: the exposure amount of the loan at the time of default (EAD), the probability that the borrower will default over the specified period of time (PD) and the fraction of the exposure amount that will be lost in the event of default (LGD). For each borrower, the EL is calculated as follows:

$$\boldsymbol{EL} = \boldsymbol{EAD} \times \boldsymbol{PD} \times \boldsymbol{LGD}.$$

The objective is to calculate the **expected losses conditional on a given climate transition scenario**. This requires to translate the impacts of the scenarios into the three determinant components of the EL described above. Nevertheless, for the moment the more matured studies have been **principally focused on the PD modelling**. This section presents an example of a common approach used by the banking industry to capture **the transition risk impacts on the credit quality of the portfolio of loans through shifts in the probability of default**. The approach is based on the following modules:

1) **"Bottom-up" module or borrower-level calibration:** Banks are interested in understanding their credit risk exposure at a granular segment (borrower-level). Unfortunately, scenario models provide a high-level overview of transition risk impacts at sector or geographical level. Considering the complexity of this exercise, a **representative sample of borrowers with homogeneous exposures** to transition risk drivers is selected. Based on expert judgement and tailored credit analysis, the relationship between transition risk scenarios and credit risk assessment is estimated at a borrower-level.

   To translate scenarios into credit risk measures, quantitative and qualitative considerations must be considered. For example, the probability of default can be impacted by quantitative factors, such as the impact on cash flows of emission costs, but also by qualitative factors, such as the borrower's adaptability to the new low-carbon environment. Scenario models provide a high-level overview of these drivers but do not specify the impact on costs/revenues for borrowers relative to their overall financial performance, neither provide information about the borrower's adaptability to the new environment. Therefore, using their experience and analytical tools, **credit risk and sustainability experts within the bank play a crucial role**, estimating the borrower's creditworthiness sensitivities to the risk factors pathways provided in the scenarios.

2) **"Top-down" module or portfolio impact assessment:** As described above, for the sample of borrowers, quantitative and qualitative methods may be used for assessing the changes in PD derived from the transition risk. The credit risk assessment at the sample-borrower-level is extrapolated to the whole portfolio through calibrated parameters and expert judgement, reducing the requirements in terms of time and resources, while maintaining the accuracy of the results.

Illustration of the proposed climate transition / credit risk methodology

1) Defining Climate Scenarios

Each transition scenario helps to assess the economic impacts on sectors

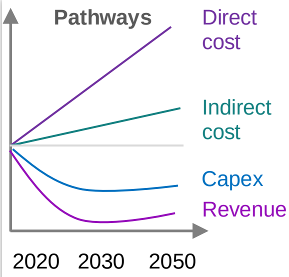
Transition Scenarios

- **Policy change**
- **Technology change**
- **Preference change**

2) Estimating economic and financial impacts

Risk factor pathways by sector/geography

Interpreting economic scenario impacts in corporate financial terms



Level of Impact	Sector h	Sector h
Direct emissions cost	High	Low
Indirect emissions cost	Moderate High	Low
Low-carbon Capex	Moderate	Moderate
Change in revenue	Moderate	High

3) Translating financial impacts into credit risk measures

Borrower-level Calibration
Bottom-Up Approach

Sample of representatice borrowers: by sectors / geography

Borrower's characteristics: financial profile, business model, credit rating...

Risk factor pathways

- Sector/geography-level
- Sensitivities to risk factors

Financial Impacts

- Borrower's cashflows and balance sheet structure

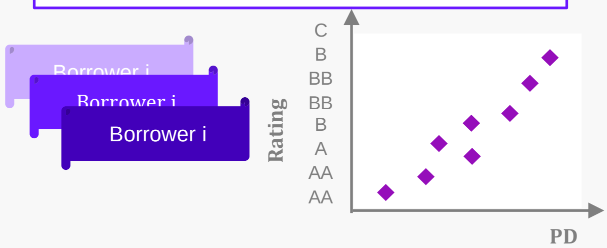
Credit risk modelling (borrower i)

Quantitative and qualitative assessment

- Internal Credit Risk Tools (e.g. Merton Distance to Default Model)
- Internal Credit Rating Models

Porfolio Impact Assessment
Top-Down Approach

Changes in the creditworthiness of the borrowers in the sample are extrapolated to the overall portfolio using calibrated parameters and expert judgement.



Systematic and repeatable approach for the rest of the borrowers in the portfolio

Parameters

For ex: **The Climate Credit Quality Index** for the Merton Model

Internal Rating

Climate-adjusted internal credit rating score

Outcomes:

Stressed parameters: PD, LGD → **Impact on Expected Losses**

3.1.4 Dedicated focus on quantitative models for the expected losses calculation

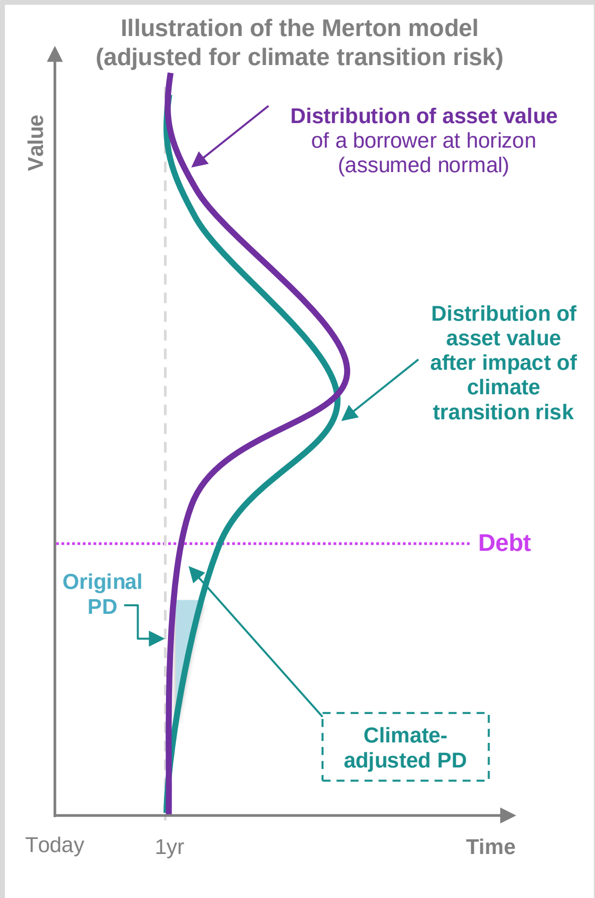
In this section, addtional details on the quantitative modeling of adjusted credit risk parameters (PD and LGD) is shared to better understand the modeling component in the translation of financial imapcts into credit risk metrics. As described previously, the PD and the LGD are important parameters used to estimate portfolio's expected losses. We present some of the actual modelling approaches to assess these parameters under different transition scenarios.

a) Assessing the probability of default (PD)

<u>The Merton Model</u>

For the quantitative assessment in the PD changes due to transition risk, the most common approach used in the banking industry is based on the well-known Merton Distance to Default (DtD) model (based on Robert Merton's bond pricing model, 1974). This model links the PD to the likelihood that the future value of the firm's assets falls below a threshold limit defined by the firm's liabilities, preventing the firm to repay its financial obligations and hence, triggering the default.

The Merton model is adapted to assess transition risks by **subtracting the net present value of all transition costs** (e.g. cash-flows and business write-offs**) from the current valuation of the firm's assets.** To estimate the shift in the asset value distribution of a borrower due to the transition costs, **an additional systemic risk factor related to the transition scenario is introduced into the model**. Letting idiosyncratic and other systemic factors unchanged, the shift in the distribution of the asset value will enable to estimate the PD variations resulting from the transition risk.



There are **several quantitative approaches to assess these PD shifts** using the Merton PD original formula. Some of them adjust the formula with the **amount of a firm's carbon footprint** (measured as the amount of CO2 emissions) and **the carbon intensity** (measured as the ratio of C02 emissions and firm's revenues), while other ones adjust the original formula by a **"Climate Credit Quality Index".** This last approach is going to be detailed below.

$$PD_i|_s = N\left[N^{-1}(PD_{i,TTC}) - \underbrace{\frac{1}{\alpha_h}\sum_r (s^r_{j,h} \cdot f^r_h)}_{\text{Climate Credit Quality Index (For sector-geography j)}}\right]$$

Climate Credit Quality Index
(For sector-geography j)

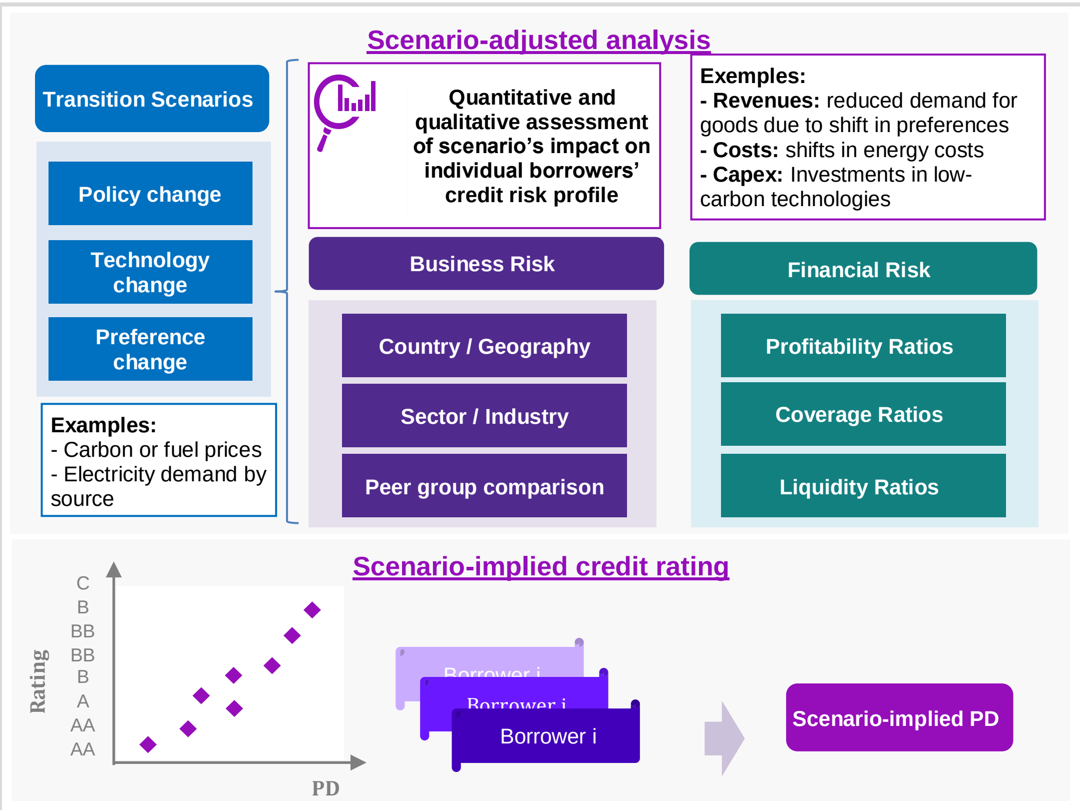
Where:

$\boldsymbol{N}$:	Standard Normal Distribution
$\boldsymbol{PD_i\|_s}$:	PD for **borrower i** under a **climate scenario s**
$\boldsymbol{PD_{i,TTC}}$:	Original through-the-cycle PD for **borrower i**
$\boldsymbol{\alpha_h}$:	**Calibration factor** for the **sector h**
$\boldsymbol{s^r_{j,h}}$:	Calibrated sensitivity to the **risk factor r** in **segment-geography j** and **sector h**
$\boldsymbol{f^r_h}$:	**Risk factor pathway r** in **sector h**

The “Climat Credit Qualitiy Index” is the result of a calibration factor (α_h) multiplied by the sum of the products of the risk factor pathways (f_h^r) and segment sensitivities $(s_{j,h}^r)$. The risk factor pathways (f_h^r) determine how risk factors evolve over time, the calibration factors (α_h) estimate the overall magnitude of climate risk impacts in a given sector h, while the calibrated sensitivity parameters $(s_{j,h}^r)$ reflect the relative contribution of each risk factor at each sector-level. Both calibrated factors and sensitivity parameters are fit to calibration points. The first one is calculated using a least-squares optimization that fits the risk factor pathways to the calibration points, while the second one is specified by experts, reflecting their qualitative assessment of the relative ranking of risk factor impacts on segments/geographies in a given sector. With this approach, probabilities of default resulting from a low-carbon transition can be estimated for defined sectors/segments within sectors or geographies and transition scenarios. It is important to highlight that **the calibration process allows for customizations defined by bank experts**, such as the definition of sensitivities, segments and calibration points.

Adjustments to Internal Credit Rating Models

Banks also leverage on existing internal rating models to assess the expected changes in PDs related to a low-carbon transition. Scenario models provide insights of carbon prices, costs and demand, as well as low-carbon technology costs. Bank credit experts can then estimate the impact of these variables into the financials of the selected borrower, to then calculate financial performance ratios such as debt service ratios (Cash flows / Net Debt) or leverage ratios (Net Debt / EBITDA). Even with this quantitative approach, the expert judgement is necessary to re estimate the borrower’s PD or internal credit rating, as assumptions about the borrower’s behaviour should be considered (e.g. future firm’s investments in low-carbon technologies), as well as the firm’s competitive position, the industry characteristics, the country risk outlook and other qualitative elements.



b) Assessing the Loss Given Default (LGD)

The LGD generally depends on the value and type of collateral available to back the loan. The methodological approaches to assess the LGD impacts in the context of the transition to a low-carbon **economy are immature and under development**. A simple approach linking the borrower's LGD to a sector specific LGD level will be a pragmatic solution. This approach may require expert customized assessments to determine the sector-specific LGDs. For instance, the analysis of "stranded" or unexploitable assets (e.g. for major oil and gas counterparties) should be considered when determining the effects of climate change on collateral assets. On the other hand, more rigorous approaches will be based on the observed correlations between the PDs and the LGDs. Thus, the forecasted LGD will depend on those correlations and the stressed PDs estimated as detailed in the previous section.

3.2 PHYSICAL RISKS AND CREDIT RISK MODELLING

As outlined in the first section of this paper, physical risks can affect borrowers in several ways. This may be for instance through increased operating costs due to more expensive supplies, a change in revenues due to decreased production capacity after damages caused by extreme events, or decreased property value of assets situated in high-risk locations. The common consequence to all these risks is **a change in borrowers' financial health and thus their creditworthiness.**

Physical risks can be **acute**, i.e. be event-driven with an increase in the severity of extreme weather events such as typhoons and floods; or **chronic**, i.e. related to more progressive and longer-term shifts in climate patterns that may cause a rise in sea level and increase in heat waves frequency for instance.

Similarly to transition risks, the main objective of the physical risk and credit risk modelling methodology is to estimate the effects on the bank's **credit risk exposure at borrower and portfolio level.**

3.2.1 Physical risk scenarios. To identify the most useful scenario sources for financial assessments of physical risk, banks should ideally consider four different components[2]:

- **The type of climate hazard**: floods, wildfires, cyclones and hurricanes, seal level rise, etc.
- **The region of the analysis**: this can be worldwide or focused on a specific geographical area (e.g. worldwide, to analyse multinational companies with a global presence or focused on a geographical area, to analyse households of a specific city, for instance).
- **The regional granularity to use**: For the most accurate analysis, and assuming that the required data is available, analysis should be performed at a disaggregated level within the considered geographical area.
- **The climate change severity and trajectory considered.**

Although tools and methodologies to assess physical risks **are still at an early stage**, initial frameworks and studies have been introduced by working groups and pilot exercises, some of them focusing on specific economic sectors that are particularly vulnerable to physical risks. Indeed, for sectors such as **agriculture or energy** which are exposed to both chronic and acute events, physical risks will **impact revenues** mainly through the production process resulting in a change in their cost of goods sold. For other sectors such as **the real-estate** which are more vulnerable to extreme events, the impact on revenues will mainly come **from a change in their property value**.

[2] Integrating Climate Risks into Credit Risk Assessment – Council on Economic Policies.

Thus, as highlighted by initial works on this topic, the methodology to estimate climate physical risk's impact does not necessarily have to be unique and universal. It could on the opposite be adjustable to fit the segment of companies under assessment and the sector in which they operate. While a couple of methodologies and frameworks have been introduced these last years, the next section presents two of these methodologies that are sector-specific:

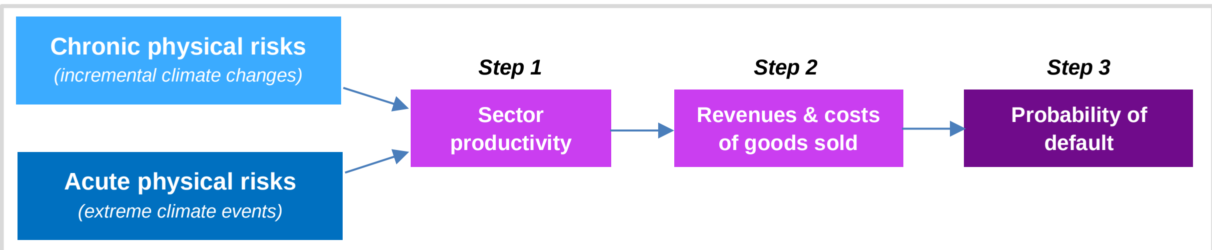
- A first methodology focusing on **sectors such as the agriculture** and energy to analyse climate-related impacts on **borrower revenues** and estimate changes in **probability of default**.
- A second methodology, for sectors **such as real-estate**, to assess the potential changes in property values and **loan-to-value ratios** due to extreme climate events.

The following section gives more details on both of these two methodologies.

3.2.2 Physical risk impacts on probability of default and Loan-to-Value ratios

a) Physical risk impacts on probability of default

This first methodology to assess impact of physical risks on borrowers' probability of default follows three steps. First, it assesses the impact of both incremental climate changes and extreme climate events on the sector productivity. Second, the resulting impacts are translated into a change in the borrower's revenues and costs of goods sold. Finally, the resulting metrics are incorporated into the bank's internal rating models in order to assess the revised probability of default.



Step 1. Assessing changes in sector productivity. The first step of this methodology is to assess the changes in sector productivity that should be analysed through both types of physical risks:

- **Incremental climate changes (chronic)** such as the rise in temperatures and change in precipitation patterns that can have considerable impacts on the productivity of several sectors, and more generally on the broader economic activity. Although vulnerabilities to these changes vary from a sector to another, making it difficult to build a common and multi-sectoral approach, the assessment of the impacts on productivity can be estimated based on peer-reviews and published literature related to climate change impact assessment.
- Regarding **extreme climate events (acute)**, the impact on productivity is to a certain extent simpler to assess as it can be estimated based on "real" productivity losses experienced during past climate extreme events (e.g. for agriculture, this could be the proportion of production lost after crop damage resulting from drought or hurricane damages – For energy, this could be the downtime of power plant during an extreme weather event).

Step 2. Adjusting income statement metrics. Once the impact of **both incremental climate changes and extreme climate events** on future sector / sub-sector productivity have been estimated, the next step is to translate these impacts at a borrower level through adjustments to its future revenues and costs of goods sold (COGS).

For most sectors, changes in revenues are driven by two main parameters which are **productivity** and **prices**. The main assumption in this second step is that the percentage changes in productivity and price for industry sub-sectors in a specific world region are assumed to translate into equivalent percentage changes in annual revenue for all borrowers in that industry sub-sector and region.
As some sectors may be able compensate a decrease in productivity by an increase in prices, while other sectors may not, this methodology assumes a couple of considerations and simplifying assumptions that are detailed below through the example of agriculture and energy sectors:

- For the **agriculture sector** (or businesses in similar sectors), changes in revenue take into account the changes of both the productivity and prices. This could eventually result in smaller revenue movements if the decrease in productivity is compensated by an increase in prices.
- For the **energy sector**, the ability to pass the decrease in productivity to customers through an increase in prices is less straightforward as this depends on whether the utility is regulated or not. Thus, a simplifying assumption for the energy sector could be to exclude price movements and only consider the changes in productivity.

Step 3. Determining changes in probability of default. Once income statement metrics are adjusted with both chronic and acute climate events, the next and final step is to incorporate the resulting "stressed" revenues and costs of goods sold (COGS) in the bank's internal rating models, the objective being to assess the **revised probability of default**. This process should be performed for each time period and climate change scenario considered in Block-1. To be noted that for practical reasons, while parameters other than revenues and COGS may also vary and affect borrower's financial performance, a simplifying assumption could be to consider that those remain constant.

Depending on each bank and the composition of its lending portfolio and exposure across sectors, this 3-steps process can be applied to a specific sample of borrowers that are sufficiently representative of the bank's global portfolio, and then extrapolate the outcomes to the rest of borrowers in similar sectors. This will allow to have a global view of the impact of climate physical risks on the bank's credit risk.

b) Physical risk impacts on Loan-to-Value ratios

This second methodology focuses on the impact of physical risks, and more specifically **acute risks** (i.e. extreme weather events), on property values and thus on the **Loan-to-Value ratios**. This two-steps methodology is applicable to retail mortgages and income-producing real estate.

Step 1. Estimating impacts of extreme events on property values. Property values can be influenced by a wide range of parameters such as the location of the property, its size, the rental income, the offer and supply demand, etc. Today, in addition to these parameters, the exposure to extreme weather events is also a key driver of property values as it directly impacts the **owner’s perception of risk**.

These last years, identification of risky zones in terms of exposure to extreme events has been simplified mainly thanks to the publication by government agencies of documents such as flood risk maps whose aim is to help real-estate investors and future homeowners take fully informed decisions. This only strengthens investor’s perception of risk as they place more emphasis on climate physical risk in their decision making process, translating eventually into an **impact on property values**.

The purpose of this first step is for banks to perform a **high-level estimation of extreme events impacts on the value of properties** they have exposures on. Price reduction of properties that have experienced extreme events in the past is estimated to be in a range between 5% and 20%. Banks can however perform a more detailed analysis on their own portfolio to refine this estimation and obtain a more accurate impact assessment.
Others factors such as market conditions, changes in weather-related design standards, etc. may also have an impact on property value. A simplifying assumption could be to exclude these other drivers and only consider the exposure to extreme events.

Step 2. Translating the impact on property values into change in loan-to value ratios. Once the high level impacts on property values are estimated, the next step is to identify the properties that are at risk and to calculate a **revised Loan-to-Value ratios**.

To this end, the resulting outcomes of scenarios defined in block-1 are translated into probabilities that properties experience extreme climate events over the average remaining mortgage term of the bank’s portfolio. These probabilities are then, for each extreme event, multiplied by the high-level estimates of changes in property values (as defined in step 1) and the results are aggregated, to calculate the ‘risk to property value’ for each climate scenario and time period, across all relevant extreme events. The final step is to derive the **revised LTV ratios** by adjusting the original property values by the risk to property value.

4. FUTURE CHALLENGES

For the past years, central banks, supervisors, working groups and the banking industry have been working together to promote the contribution of the financial system in the global fight against climate change. As exposed in this document, transition and physical risks are a source of structural changes that will affect the global economy and the financial system stability. As stated before, climate-related risks impact the traditional financial risks and as a result, should be **treated as key drivers of the existing categories such as credit risk, market risk, liquidity risk and operational risks.** Moreover, banks should integrate climate risks into their business model analysis, strategy definition, financial planning, governance, risk appetite definition and disclosures.

Regarding the integration of climate risks into credit risk modelling, as is the focus of this document, banks will need to account for climate-related risks at all stages of the lending process, from the granting and pricing of loans, to the collateral valuation, the quantification of credit risk metrics, the monitoring of exposures and limits and the credit risk policies and procedures. Related to the quantification part, the methodological approaches to quantify the impacts of climate risks on borrower's creditworthiness **are still at an early stage of development and further analysis and improvements are required and expected for the coming years.** Some challenges such as expanding the horizon of the models, designing climate scenarios for financial risk analysis, solving the problems related to the lack of granular data, identifying the relevant climate risk exposure metrics or adapting the actual risk tools for climate risk modeling need to be addressed. Due to the complexity of the methodologies and the high degree of diversity between the physical and transition scenarios, **expert judgment will be highly demanded** when assessing the economic and financial impacts of climate risks.

Finally, the transition to a low-carbon economy will take time as number of unknowns are remaining. Nevertheless, the early banks will start to adapt their actual business model and risk management frameworks, the better they will be prepared to mitigate the transition and physical risks of climate change. Besides, once the potential risks and opportunities posed by climate change will be better assessed and understood by banks it will be easier for them to adapt and provide the adequate support to their clients.

HOW AVANTAGE REPLY CAN HELP?

Avantage Reply (a member of the Reply Group) is a pan-European specialized management consultancy delivering change initiatives in Risk, Finance, ALM, Treasury and Compliance within the Financial Services industry. Founded in 2004, Avantage Reply provides subject matter expert advisory for key ALM, Finance & Risk hot topics on CFO and CROs agendas. Our service offer **regarding climate risk management notably covers:**

Topic	Description
Business & Risk Strategy	• Advice and support to integrate climate-related issues into business planning and risk strategy (RAF) • Advice and support on embedding climate risk management into strategic processes (ICAAP…)
Governance	• Design and implementation of a climate risk management governance framework
Risk identification	• Integration of climate risk components into Material Risk Identification processes (climate risk driver identification and assessment, carbon asset risk assessment framework)
Risk management	• Portfolio analysis and sensitivity to transition and physical risk (incl. sector/geographic exposures) • Integration of climate risk components into Operational and Financial Risk Management frameworks • Design and implementation of “climate quality index” into existing credit risk models • Design and implementation of green/brown scorecard approach / green weighting factor
Stress testing / scenario analysis	• Design and implementation of a climate risk stress testing framework (interpreting and applying prescribed methodology, scenario generation linked to risks and business drivers, models/projections)
Supervisory compliance	• Gap analysis or action plan to design a climate risk management framework in line with supervisory expectations and market practices

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Services:
- Transversal SME support
- Complex program management
- Regulatory transformation

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- Stress testing frameworks
- Recovery and resolution
- Climate risk management and stress testing

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