ASSESSING CLIMATE PHYSICAL RISKS FOR FINANCIAL DECISION MAKERS

Common methodologies, challenges and case studies

Clim INVEST

Tailored climate risk information for financial decision makers

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carbone 4
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Abstract:
Climate change is happening, and its effects are already visible across the world. Human activities and businesses are being impacted in all sectors by extreme weather and climate events and chronic shifts in climate such as increasing temperature, changes in rainfall patterns and sea-level rise. These physical impacts of climate change are expected to worsen over the next few decades, threatening financial investments and activities. If the regulatory framework has evolved, with the set of recommendations issued by the Task Force on Climate-Related Financial Disclosures (TCFD) for a better climate risks reporting in the financial sector, the investors lack the tools and expertise to quantify the impacts of physical climate risks on their assets and investments. Moreover, the physical impacts of climate change are highly localized, and tailored, detailed information is needed, from climate variables to financial indicators.

This report introduces the impact chain framework that can help decision makers understand risk assessment implementation issues, and build capacity for analyzing and managing risks. This framework is further detailed and illustrated through several case studies on assets and portfolios. This report presents both the methods and the tailored information generated for the finance sector, from the assessment of vulnerabilities to the creation of financial indicators. We describe commonalities and differences across sectors, type of portfolios and data availability context. We highlight the challenges and the opportunities of the project's inter-disciplinary approach.

Full reference: *F. Gallo and V. Lepousez (2020). Assessing physical climate risks for financial decision makers: common methodologies, challenges and case studies. Carbone 4. ClimINVEST project report.*

Executive Summary.

Climate change brings two types of risks: “transition risks” are induced by the transition towards a low-carbon economy, and “**physical risks**” **are linked to the exposure to the physical consequences of climate change**.

Physical climate risks are the combination of three components:
- the climate hazard,
- the exposure to the climate hazard, and
- the vulnerability to the climate hazard.

Information on these three components is therefore required for any climate risk assessment.

Physical climate risks can have a strong impact on the finance sector. Financial systems and their actors are affected by climate change indirectly. Climate events can have a direct impact on the financial performance of economic actors and on the broader financial system. Guidance is needed to help investors understanding the complexity around risk assessment.

In this report, we describe a framework to carry out a climate risk assessment. The impact chain framework is a way to translate climate information into financial information. Climate change directly impacts the intensity, probability and frequency of climate hazards, that can lead to physical impacts on physical systems (loss of yield, physical damages on infrastructures, decrease in water resources etc.). These physical impacts can be translated into financial impacts (loss of revenue, increased operation expenditures etc.), that eventually affect financial actors (increased probability of default etc.).

The impact chain framework is a way to describe, step by step, the chain of consequences of a climate phenomenon, from its physical to financial impacts on an entity (company, asset, government…) to its impacts on the financial institutions associated with this entity. Through several case studies, we describe commonalities in assessing climate risks and highlight the challenges and the opportunities.

The level of detail of a climate risk assessment depends strongly on the input data describing the entity or the asset. Assets are impacted through their vulnerability, which depends on their specificities (e.g. physical assets, water consumption, dependencies...). It is therefore important to know about the specificities of a entity/asset to understand its vulnerability and to quantify its exposure to physical climate risks. **When this information is available, is it possible to assess the financial impacts of climate hazards on the asset. However, gathering specifc information on an asset is not always feasible**, especially for an investor. We thus highlight two alternative approaches to be run in the absence of such data: **a climate hazard exposure mapping, and a broader qualitative scoring approach**. They can both provide useful information on climate risks, and highlight the most exposed assets where **further investigation should be carried out based on more detailed asset-level information**.

The framework and potential methodologies described in this report are not prescriptive. Readers could look at this work to 1) better understand physical risks assessments and 2) improve the level of detail and accuracy of such assessments.

Finally, **gathering information on climate risks can help to manage these risks, through portfolio management and engagement with the entities/assets in the portfolio**. Such an engagement could help develop diverse adaptation measures at the entity level to reduce climate risks.

Content.

1. Introduction

January 2019. California has experienced two years of drier and warmer-than-usual conditions that led to a large number of wildfires that destroyed properties, impacted activities and led to the loss of huge forest areas. Amongst those events, the Camp Fire was the biggest wildfire in California history and the most expensive natural disaster in the world in 2018, both in terms of insured and total losses (Munich Re, 2019), with more than US$16 billion overall losses, 85 casualties and more than 19 000 properties destroyed.

January 2019, California wildfires

Dry conditions and wildfires are not uncommon in California, but many studies have shown that the frequency and the intensity of these phenomena have been increasing due to anthropogenic climate change. 14 of the 20 most devastating wildfires in state history have occurred in the past 13 years.

If the link between dry conditions and wildfires in California is established, what is less obvious is **the financial consequences that these events had on the largest Californian utility**. According to a 700-page report by the California Public Utilities Commission released in November 2019, the power producer did not properly inspect and correct hazardous conditions on one its transmission line before a faulty wire sparked the wildfire. The utility had to file for bankruptcy to face $30bn in liabilities and hundreds of lawsuits, because the ineffectiveness of its maintenance policy of equipment was identified as a trigger element of the Camp Fire. Company shareholders have watched the market value of the company plunge from from $12.4 billion to $2.5 billion in six months.

PG&E's story has been described in the press as "**the first climate change bankruptcy**".

There are **two main take-aways from PG&E's story**. The first is that despite its efforts to mitigate climate "transition risks" by commiting to a cleaner energy, **PG&E's exposure to "physical climate risks"** increased because of shifts in regional climate. Increased frequency and intensity of drought conditions and high winds in California, combined with PG&E's faulty maintenance protocol, created the conditions for widespread wildfires.

Figure 1 describes the two types of climate-related risks facing by PG&E: "transition risks" are induced by the transition towards a low-carbon economy, and "physical risks" are linked to the exposure to the physical consequences of climate change. This report focuses on the latter.

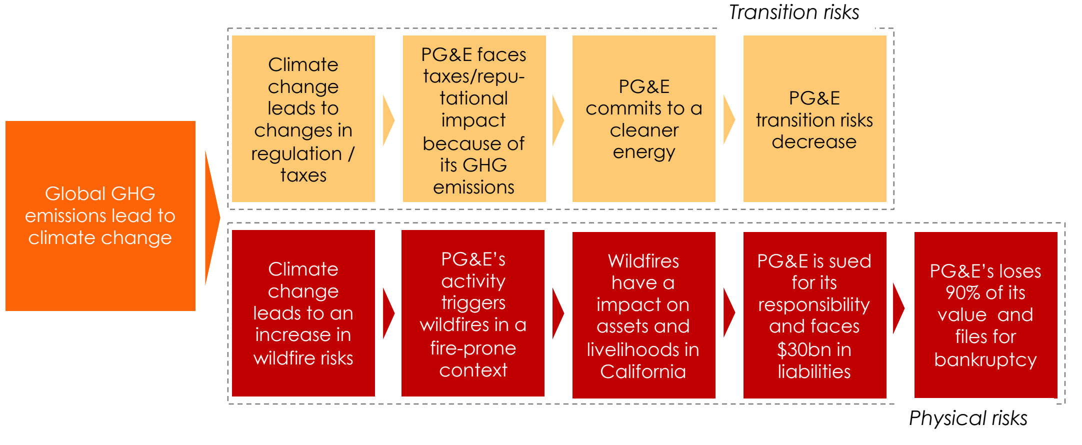


Figure 1 Schematic illustration of the two types of climate risks that PG&E has been facing in California: transition risks, linked to PG&E's carbon footprint, and physical risks, linked to the climate evolution. In 2019, the physical risks had a huge impact on PG&E. (Source Carbone 4)

The second take-away is that **physical climate risks have been proven to represent significant financial impacts, for companies exposed to climate risks but for the whole financial system**. In PG&E's example, a fall in PG&E's capitalization by almost 90% was observed in a few months. More generally, financial impacts on a company can be broken down in four areas : asset value, revenue, cost of operation and cost fo financing (TCFD, 2017). From a broader perspective, impacts on the financial system include difficulties repaying loans, decreased investments, population (i.e. customers) displacements. It is therefore important to define, when possible, a methodology to assess, qualitatively or quantitatively, the financial risks linked to climate change for the counterparts and the investors.

2. The impact chain as an assessment framework

2.1 Main commonalities in climate risk assessments

There are **three key components of physical climate risk** to consider in any analysis: 1. the climate hazard, 2. the asset exposure to the climate hazard, and 3. the asset vulnerability to the climate hazard. This report will not dive into the details of the components, but more information can be found in ClimINVEST factsheet *Climate modelling*.

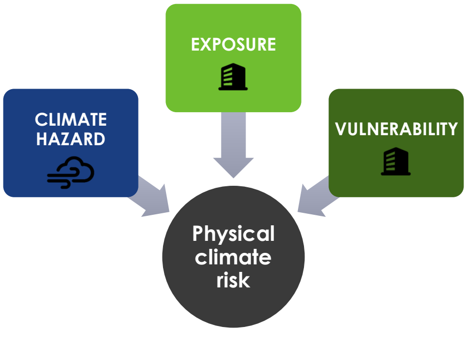


Figure 2 Climate risk is the result of a climate hazard (e.g. heatwaves), an exposure (e.g. will there be heatwaves impacting the asset of interest) and a vulnerability (will the asset be impacted and how much)

It is important to understand that **any complete risk assessment requires information** on climate hazard, asset exposure and asset vulnerability, even though the way to combine these three types of information might differ.

The climate hazard component is based on climate data, issued mainly from climate models. If there are challenges and limitations to our understanding of the climate system and to our ability to project the climate evolution, this part of the assessment relies usually on scientific, publicly available data.

The exposure component is the minimum asset-specific information required to carry any assessment: it corresponds to the asset location and financial value (or proxy on activities). Proxies used to capture this exposure should be carefully selected to capture the location of the real physical activities, especially for companies. For instance for a pharmaceutical industry, the location of its headquarters does not necessarily match the location of its factories nor its markets, where physical climate impacts will actually occur.

The vulnerability component of the risk assessment can be more difficult to carry on. The impacts of a climate event on an asset or a system are linked to their vulnerability. **Impacts can affect different parts of the value chain and different financial aspects** (Capital (CAPEX) and operational (OPEX) expenditure, revenues) and be linked to specific thresholds for the asset (e.g. temperature limit between snow and rain for winter tourism, maximum temperature tolerated by a system).

For a company, the vulnerability depends on the specificities of its physical assets (e.g. building materials, design), on its dependencies (e.g. high water consumption), on its links with its value chain, or on its adaptive capacity. **It is therefore important to know about the specificities of a company/asset to understand its vulnerability** to climate hazards and to build a more detailed and accurate picture of the risks faced by this company/asset. The use of a large-scale risk analysis that does not consider asset-level sensitivity or adaptive capacity (e.g. large-scale/sectoral GDP-based analysis) might provide a broad estimate of the impacts of climate change but will always grossly miss the specific impacts on an activity.

However, gathering specifc information on an asset is not always feasible, especially from an external investor's point of view. Therefore, the nature and level of detail of a climate risk assessment can strongly differ, depending on the availability of information on impacts and vulnerability:

- **a quantitative risk assessment** will provide quantified, results on expected physical and financial impacts
- **a more qualitative approach** can be used to understand the vulnerability of an asset to climate hazards and to estimate the climate risk, following a rating-based or scale-based approach (e.g. high-medium-low).

In any case, the logical frame behind the analysis is similar: when a climate event occurs, the impacts on an asset depend on its exposure and vulnerability.

In this report, we describe **a generic framework for carrying a physical climate risk assessment**. This framework is based on a generic flow sheet that enables to **translate climate risk into a financial risk information**. The impact chain framework presented in this report is therefore a theoretical guide on how to operate this translation.

Case studies are presented further in this report to illustrate the methodology for carrying a climate risk assessment, following the impact chain framework in a quantitative or qualitative way, depending on the available data.

2.2 Introducing the impact chain framework

Financial systems and their actors are affected by climate change indirectly. There usually isn't a direct link between global warming and specific financial indicators. Climate events – measured and described using climate indicators (e.g. seasonal precipitation) – have physical impacts that affect assets (e.g. natural resources availability, yields) with an impact on financial performance of the actor (e.g. through supply disruption, shut down of facilities) and the broader financial system (e.g. ability to repay loans).

Guidance is needed to help investors understanding this complexity around risk assessment. The linear framework described here is a way to explain and illustrate the translation process, following the impact chain from a climate event to its financial impacts.

In recent years, **impact chains** have been more and more used to describe how the impacts of a climate phenomenom propagates through a system or a value chain (e.g. Pramova et al., 2013; Schneiderbauer et al., 2018). Here, we apply this framework to the physical climate risks for the financial sector.

The idea is to define, step by step, **the chain of consequences of a climate phenomenon, from its physical to financial impacts** on an entity (company, asset, government…) to its impacts on the financial institutions associated with this entity (figure 3). Ideally, this whole process should be done for every climate hazard, every company/sector in every location, for CAPEX, OPEX and revenues. This method will not be easily applied for a large and diversified portfolio, we therefore present alternative approaches to incrementally assess physical climate risks on investment portfolios.

Risk assessment is a gradually improving process, and investors could look at the framework described here as a way 1) to better understand physical risks assessments and 2) to improve the level of detail and accuracy of such assessments.

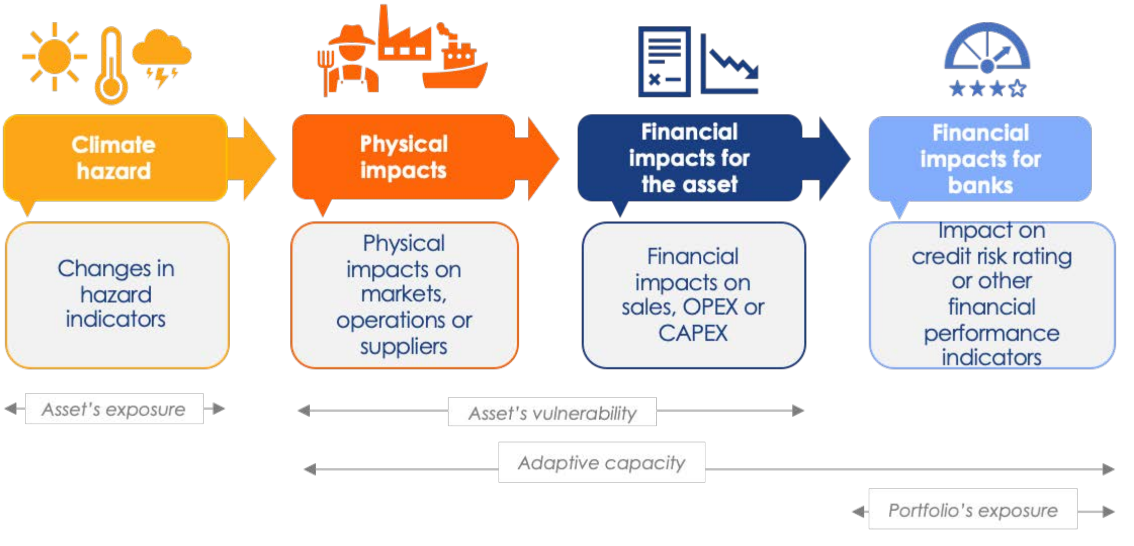


Figure 3 The impact chain approach, from climate data to physical and financial impacts (Source Carbone 4)

The following sections describe how to assess each step of this impact chains and their respective challenges, and present several case studies that illustrate the impact chain. The case studies presented in this report arise from the collaboration between financial institutions and climate specialists partnering in the ClimINVEST project. These case studies should not be seen as definitive or prescriptive but merely as examples to illustrate potential ways to carry out a climate risk assessment for a financial actor.

2.3 How financial actors can use impact chains

As stated above, the impact chain approach presented in this report provides **a general framework to ensure proper identification and analysis of physical climate risks**; such a framework can be applied to the needs of all financial practitioners, for portfolios in different sectors and geographies, and for different time horizons.

Financial actors can use this approach not only for carrying out risk assessments but also as a guidance on the different stages of risk decision making, as classified in previous ClimINVEST report (reference to CICERO investors needs report):

- **Raise risk awareness**:
  - Impact chains help identify concretely how climate hazards may generate impacts on portfolios
- **Build capacity for risk analysis**:
  - By looking at each step of the analytical process, impact chains help understand which specific data and tools shall be used
  - This can be a first step towards collaboration with relevant partners to design a physical climate risk analysis tailored to the needs of the financial actor
  - This can also be used as a checklist to challenge risk analyses carried out by others (e.g. Is the level of detail appropriate?)
- **Build capacity for managing the risks**:
  - By improving understanding of the risk on the asset/entity, impact chains can help identify adaptation opportunities to discuss with the entity.

The following sections of this report explain how impact chains can be used to carry out physical climate risk analysis, with emphasis on the recommended data and tools. In particular, it explains how to carry out the analysis when the ideal set of precise data is not available. Indeed, previous ClimINVEST work shows this is often the case (I4CE, 2018).

3. Using impact chains to understand tools and data needs for risk analysis

3.1 Overview of the cascading flow of information

Figure 4 shows **how to read and use the impact chain framework with one particular easily understandable example on agriculture**. From right to left : the probability of default for a crop producer can be directly linked to its revenue hence its production level ; agricultural yield can be directly correlated to climate indicators (one only or a combination of several indicators). However (from left to right) to evaluate the impact of climate change on agricultural yield, field-specific information is needed and impact functions too. To translate decreased production into financial impacts, other information is needed such as market prices. At last, to assess the financial impacts for the financial actors, information on risk management is needed.

Correlation models between climate hazards and financial impacts (the 2 extreme parts of the impact chain) exist in very rare cases at the asset level, usually for weather sensitive asset with detailed historical activity reporting. It then usually correlates financial impacts to a generic climate indicator such as increase in temperature without identifying the physical impacts behind the correlation, or focus on only one physical impacts. It is therefore potentially incomplete and results must be interpreted carefully.

At the portfolio level, current monetised approaches providing financial results at the portfolio level usually overlook step 2 – the tailored analysis of the physical impacts of each climate event on each activity.

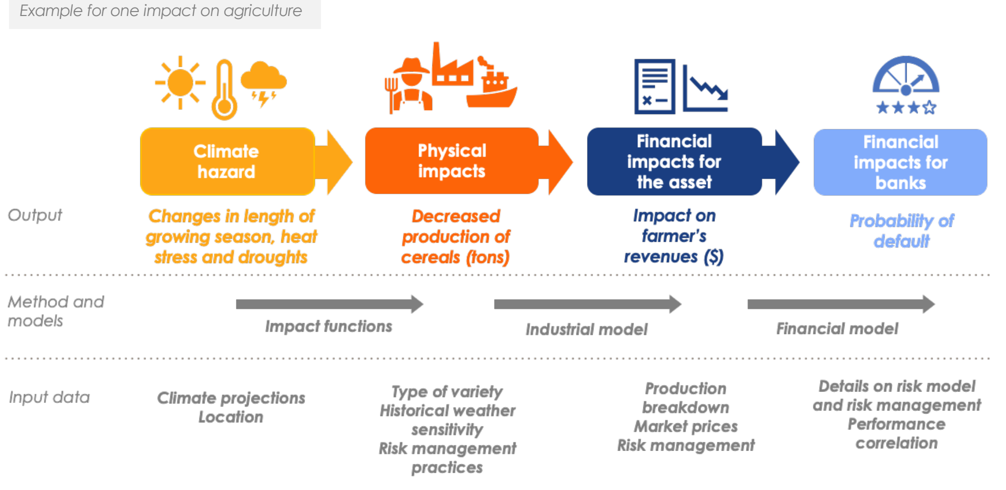


Figure 4 The impact chain approach, illustrated for one particular impact on agriculture (Source: Carbone 4). The list of input data is not exhaustive.

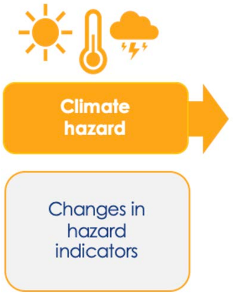
In the following sections, the analytical approach behind each step is described, and data challenges explained.

3.2 Identifying the appropriate tools and data at each step of the impact chain

This framework requires **a step-by-step approach** and specific information at each level. The next few paragraphs describe the type of tools and data required to progress along the impact chain.

- Starting with from climate data to climate hazards
- From climate hazards to physical impacts for the asset
- From physical impacts to financial impacts for the asset
- From financial impacts for the asset to the financial institutions
- Financial actors may consider the explanation below either for carrying out their own risk analysis or for engaging dialogue with other relevant stakeholders on physical climate risk analysis.

3.2.1 Starting from climate data to climate hazards



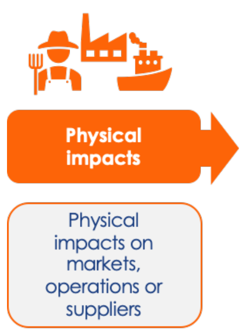
Summary of analytical approach

- Identify **the most relevant and priority climate hazards, based on the asset vulnerability**. For instance, heatwaves would be very material for the construction sector but less so for non material services. *See Annex 1 for a non-exhaustive list of sector-specific impacts.*
- Climate indicators describing the hazards are derived from raw climate data (see ClimINVEST factsheet on *Climate modelling, scenarios and time horizons* for more details on this process). These indicators are used to assess the frequency and intensity of climate hazards at the asset's location to **determine the asset's exposure**.
- For each hazard and sector, climate indicators can be identified (e.g. specific climate attractivity indicators for tourism). Depending on data availability, the indicators can be specific to a sector/project (see below) or more generic. *Examples of relevant sector-specific indicators have been compiled by the ClimINVEST project and other initiatives (e.g. Copernicus…) - See Annex 2 for a non-exhaustive list of sector-specific indicators.*

Sources and types of data

- **Climate indicators are provided by climate experts.** Many indicators have been computed and are available on different data portals, such as the Copernicus Climate Data Store.
- Climate indicators can be **asset/company-specific, sector-specif, or more generic**. The more specific the indicators are, the more accurately they will describe the exposure of the asset. However, generic and sectoral indicators are usually more available on data portals, whereas asset-specific indicators might have to be defined through a co-construction process with sectoral experts. This is often beyond the scope of an investor's climate risks assessment.
- Climate data can be supplemented with local, contextual data (land use, specific aggravating factors…) to capture climate-related hazards (e.g. floods, landslides, coastal erosion, biodiversity loss). Contextual data can be provided by local or national environmental agencies or international institutions (e.g. FAO).

3.2.2 From climate hazards to physical impacts for the asset



Summary of analytical approach

- There is currently **no established equation or catalogue of impacts that can be used reliably across sectors** to translate climate indicators into physical impact. Calculations, where they exist, are sector-specific: for example, the impacts of increasing temperature on crop yields have been calculated for some crops. These links between climate data and physical impacts are called **impact functions or damage functions**.
- The complexity of the impact functions side can lead, for some sectors and impacts, to **a large global uncertainty if misused. Therefore, the use of universal impact functions (e.g. a function linking the temperature rise to the evolution of global GDP) is to be avoided**. In theory, the physical impact of each climate hazard would be calculated for each asset. In practice, this quickly becomes too complex and unmanageable for investors at the portfolio level. Global investment portfolios are exposed to all sectors and regions at once, as well as all the diverse climate events that entails. It can be helpful to consider the impact of generic climate hazards on portfolios at the sector level in its geographical context to gather information on the sector vulnerability.

Sources and types of data

- **Quantified sector and asset-specific climate impact functions** are developed from historical data on damages from previous climate events or expert judgment. Such impact functions are available in some sectors (e.g. heating distribution, impact of temperature of workers' productivity) and need to be further developed and catalogued for many others. For example, it is quite straightforward to link rising temperature with increased energy use from air conditioning systems (see the case study further in this document), but it is much less simple to calculate the impact of more intense precipitation on a bridge. When existing, impact functions can be found in in the scientific literature as well as in national and international standards.
- **Information on large scale, sectoral vulnerability can be found in the scientific literature and in sectoral assessments** (e.g. the impacts review in the IPCC assessments reports, the EEA Climate-Adapt portal). Such information is usually broad and qualititative (e.g. low-medium-high vulnerability, vulnerability rating).

3.2.3 From physical impacts to financial impacts for the asset

Summary of analytical approach

- For some impacts, including OPEX (e.g. increasing air conditioning costs due to higher temperatures) or sales, the financial impact can be calculated directly from physical impacts information but this is not always the case. (For example, on CAPEX, even though the physical impacts of a climate event can be quantified (step 2 described above), more information (value of the asset, contribution to the revenues) might be needed to calculate how it translates into financial impact.
- **This calculation requires activity or asset value data** in order to link the physical impact with its financial consequences on the asset.

Sources and types of data

- Activity data or assets' values are usually provided by the company, especially for large, listed companies (mandatory reporting). **The level of detail differs strongly from one actor to another**. It is more difficult to access data for smaller companies. Gathering and managing relevant financial data is one of the main challenges of quantitative impact chain assessments.

- Some databases exist but generally their level of coverage needs to be carefully assessed as they generally do not gather all necessary data or with unsufficient granularity. Moreover, a large number of these datasets are operated by private companies and non freely available.
- Financial data from past climate events can be used to inform assessments (e.g. the financial impacts of a warm winter on the revenue of a ski resort; the impacts of a flood-related shutdown of a mining site on annual production and sales). Financial impact can be observed on sales, CAPEX and OPEX.
- **When no company or asset-specific financial data is available**, a sectoral approach can be applied (e.g. global average of the financial costs of a flood on real estate). **The financial impacts can also be defined on a broad, qualitative scale** (e.g. low-medium-high impact; financial impact rating).

3.2.4 From financial impacts for the asset to financial impacts for financial institutions

Approach

- Once the financial impacts of a climate event on a given entity have been assessed, this information can be processed to **quantify its impact for the financial actors**, e.g. banks, asset managers, investors.
- The financial information generated at the previous step needs to be integrated in financial models and internal risk analysis for the financial institution.
- When only broad, qualitative information is available on financial impacts on the portfolio's financial assets (e.g. financial impact rating), a simplified aggregation of ratings can be done at the portfolio level (e.g. weigthed average the ratings of each financial asset with the portfolio)

Sources of data

- As **the calculation of financial performance indicators often relies on proprietary models within financial institutions**, this last step will usually be performed in-house by those institutions. Whatever the type of output (quantified, relative) the important point here is that the previous calculation steps must lead to an output that is usable by the financial actors in their processes.

3.3 About the data challenges

The impact chain framework is a bottom-up analysis that requires specific data on both the climate hazard and on the asset (a company, an infrastructure, a building etc.). The relevance and the accuracy of the analysis therefore depends strongly on the quality and availability of the data describing the portfolio (figure 5).

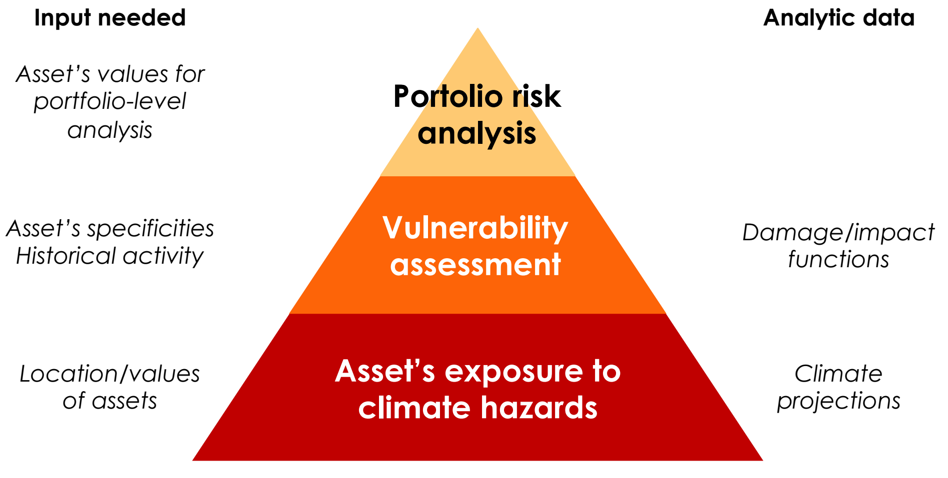


Figure 5 Data challenges on physical risk assessment. (Source Carbone 4)

The availability of reliable, relevant data is one of the major challenges in climate risks analysis.

- **On the climate data side,** it is important to note that the accuracy of climate indicators depends on many factors, the first being the ability of climate models to accurately simulate a given variable (e.g. better performance for temperature-related indicators than for wind data). Some hazards are not pure climate hazards and might require non-climate data or location specific data to be assessed (e.g. flood hazard is related to both rain and soil properties, elevation, land use, etc.).

- **On the portfolio side**, a detailed analysis requires detailed input data on its investments (e.g. companies' activities and sites, accurate location of assets or suppliers, assets' specificities, type, age and energy performance of buildings for a real estate portfolio). This level of information might not be easily available for a financial actor. It is therefore important to keep in mind that **the level of detail of the risk analysis depends strongly on the level of detail of the portfolio description**. The mapping of the required information for a thorough risk analysis can be the first step towards better data management, which will lead to a more detailed risk assessment in the future.

4. Case studies and perspectives

The following pages describe some of the case studies that were developed during the ClimINVEST project. **These case studies are here to illustrate the framework** and should be seen as possible ways to carry out a climate risk assessment. Four case studies are decribed:

- a tailored climate exposure assessement for an agricultural portfolio;
- a quantitative analysis of the impact of increasing temperature on the revenues of a heating distribution network, based on specific data for the asset;
- a qualitative climate risk assessment on a real estate portfolio in France, combining hazard exposure quantification and qualitative impacts scoring;
- a qualitative climate risk assessment on an international, multi-sector portfolio.

4.1 Case study 1 – Climate exposure assessment on an agricultural portfolio

The impacts of climate change on agriculture, and especially crop production, have been investigated in numerous studies (e.g. see references in IPCC, 2014). If the recent trends in temperatures have benefitted crop production in some high-latitude regions, these studies show **a global negative impact on yields for many common crops** (especially wheat and maize). Impacts resulting from future climate change are expected to be similar, with **most regions suffering negative impacts** and only a few locations benefitting from climate change. Some studies estimated that *negative impacts on average yields become likely from the 2030s* and that *negative impacts of more than 5% are more likely than not beyond 2050 and likely by the end of the century* (IPCC, 2014).

These expected negative impacts on yields, as well as potential changes in climate interannual variability can affect the financial stability of crop producers.

Linking crop yields to climate variables is possible but requires specific crop modeling that is probably beyond the scope of a simple risk screening for a portfolio. In this example, we had very few information on the portfolio. We had only the location and area of each fields. We therefore proposed a simple, tailored climate exposure analysis to estimate the evolution of the portfolio exposure to climate hazards.

Methodology

Linking crop yields to climate variables is possible but requires specific crop modeling that is probably beyond the scope of a simple risk screening for a portfolio. In the absence of such impact functions, we used a simple, tailored climate exposure analysis to estimate the evolution of the portfolio exposure to climate hazards.

This exposure analysis investigates the frequency of hot days that can cause damages to the crop and reduce its yield. The threshold temperature was set to 30°C (the optimum temperature range for wheat being 12-25°C). The IPCC indicates that crop yields have a large negative sensitivity to temperatures around 30°C (IPCC, 2014).

Please bear in mind that this example should be used for illustrative purposes only and 1) does not describe the sensitivity of the different wheat varieties to heat and 2) does not constitute an exhaustive analysis of wheat sensitivity.

In this example, **only three out of four steps of the impact chain are explored** (figure 6): a specific climate indicator is calculated to investigate the evolution of a climate hazard (step 1). The physical and financial impacts (steps 2 and 3) were not quantified, but the climate indicator used in the first step is based on the crop vulnerability to heat. Therefore this climate indicator is specifically linked to the potential impact of high temperature on the crop. Finally, we aggregated the qualitative results at the portfolio level (considering the proportion of each producer in the portfolio value) to describe the potential impacts for the investors (step 4).

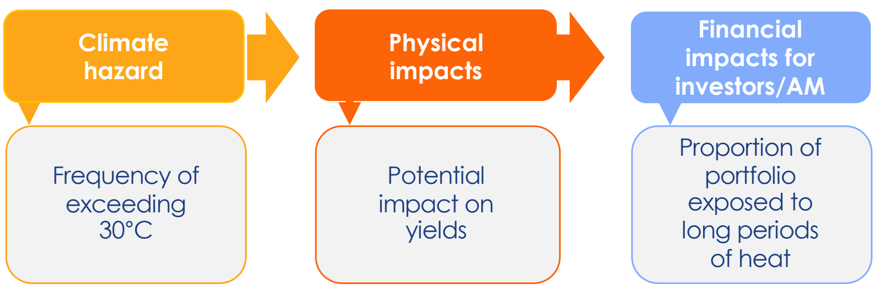


Figure 6 Impact chain for the agriculture case study

Results

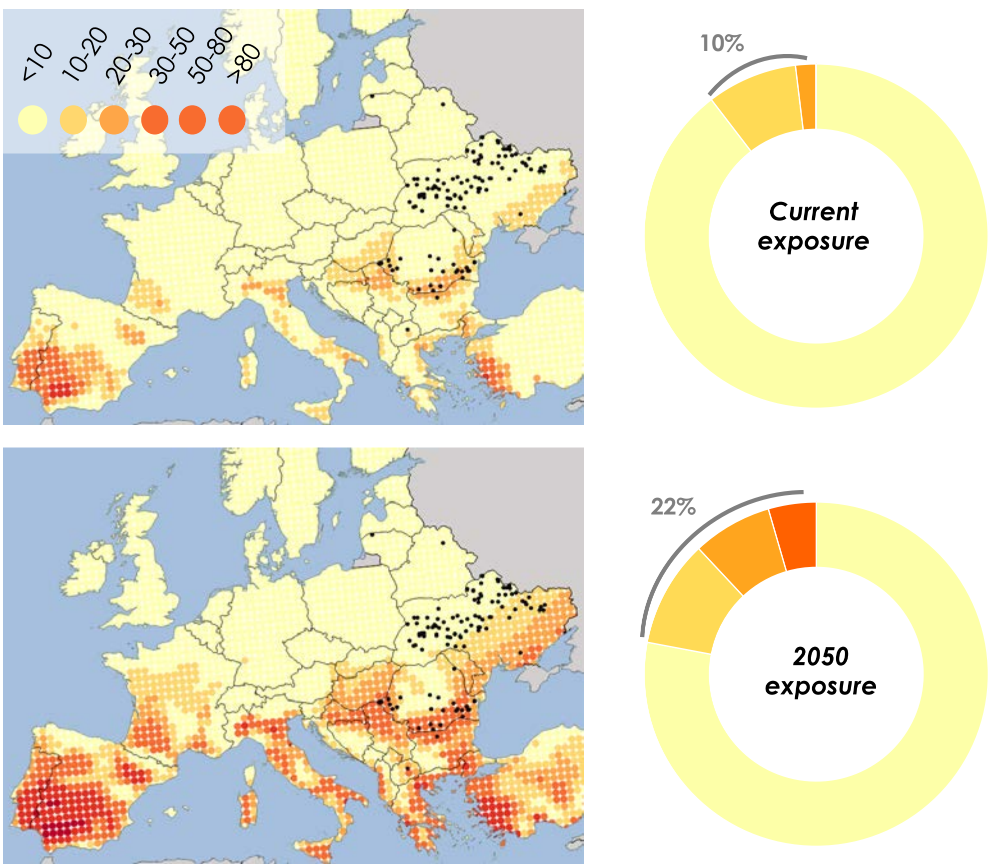
Figure 7 describes the frequency of exceedance of the 30°C temperature threshold, both for a reference period (1986-2005) and for the future (2041-2060), for a high emissions scenario (+4-5°C at the end of the century).

This frequency of exceedance describes the frequency of having hot temperatures that can cause damages to the crop or decrease yields. The higher this value, the more likely the impacts are. For each wheat producer (black dots on figure 8), we extracted and compared the reference and future values to highlight the increase in potential impacts due to high temperatures.

At the portfolio level the results show that **the proportion of the portfolio (in value) exposed to more than 10 hot days per year on average increases from 10% to 22%**.

Despite being purely climate-focused, the results deliver information on the probability of a crop failure in the next decades and on the financial instability that such an event could trigger.

Portfolio's exposure to heat-related impacts on agriculture



Map of exposure levels to heat in Europe based on the Frequency of exceedance of a 30°C temperature threshold (days/year)

Distribution of the exposure levels to heat-related impacts for a given portfolio

Figure 7 Exposure assessment of a European Farming&Plantation portfolio towards heat stress. Frequency of days above 30°C and location of the portfolio's constituents (left top: reference, left bottom: 2050, high emissions scenario). Proportion of the portfolio exposed to more than 10 days above 30°C (right top: reference, right bottom 2050, high emissions scenario). (Source Carbone 4)

Summary

This information is on exposure only and does not give information on quantifed physical impacts or the value of financial impacts. However, **such an analysis can be useful to 1) identify the main risks for the sector, 2) identify the main regions/crops that are exposed and 3) engage with counterparts or investigate further**.

4.2 Case study 2 - Impact of increasing temperature on heat distribution

Here we describe a simple example to illustrate the whole process of following the impact chain. As average global temperatures rise around the world, the needs for heating and cooling of buildings shift accordingly. This means for example that **the needs for heating are expected to decrease with milder winters**. In this example, we assessed the impact of increased temperature on the revenue of a heating distribution network located in a major city in Europe.

Methodology

Heating degree days (HDD) is a climate indicator designed to represent heating needs at a given location. Here HDD are calculated (following the US Weather Service simplified methodology) as the temperature difference between a daily average temperature and a reference temperature (e.g. if the average temperature for a given day is 3°C and the reference temperature 18°C, HDD for this day are equal to 15). Daily HDD have been then summed over a given period, here a year, to compute annual HDD. This first processing step provided **the difference in HDD between the historical reference period and a future period, based on raw temperature datasets, for the specific location**.

The second step, **quantifying the link between HDD and sales,** required information on historical sales. In this analysis, based on historical sales, a 1:1 relationship was established, which means that a 1% decrease in annual HDD leads to a 1% decrease in annual sales (house heating only). This relationship would have to be calculated for any other heating distribution network.

The third step required information on the business model of the company. This **business model was challenged** based on the revenues decrease due to climate change.

Investors were therefore able to use this updated business model for their decision-making process, this step was carried out internally by the investors.

Figure 8 describes the analytical steps for each step of the impact chain framework. For this case study, the climate data as well as the impact data were specific to the asset. This means that the impact functions from climate data to the quantification of the different types of impacts were designed specifically for this analysis and should not be used as such for another network in any other location.

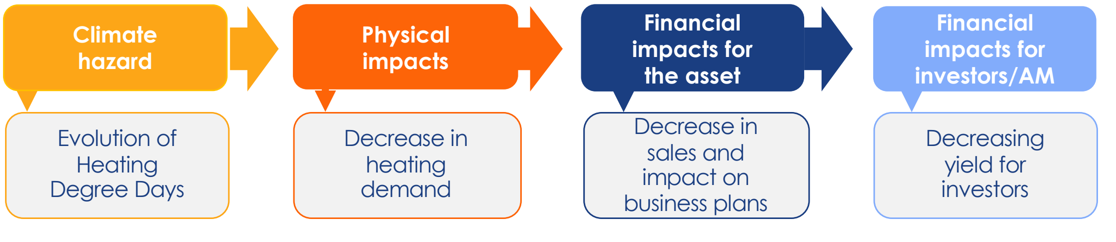


Figure 8 Description on the analytical steps and the data used for the climate risk assessment for the heating dsitribution network, following the impact chain. (Source Carbone 4)

Results

The results of the analysis show a **12-20% decrease in heating sales in 2040** for this location. The uncertainty linked to the results is due to the climate scenario and the climate models that were used.

As shown in figure 9, this information was used to challenge the business plan of the company, which was projecting that the maximum capacity of the heating distribution network (the 100 value on the y-axis in figure 9) would be reached in 2032 (blue line). The results of our analysis show that the impact of increasing temperatures on the company's revenues is expected to delay this objective by up to 7 years (under the +4°C scenario, red line in figure 9).

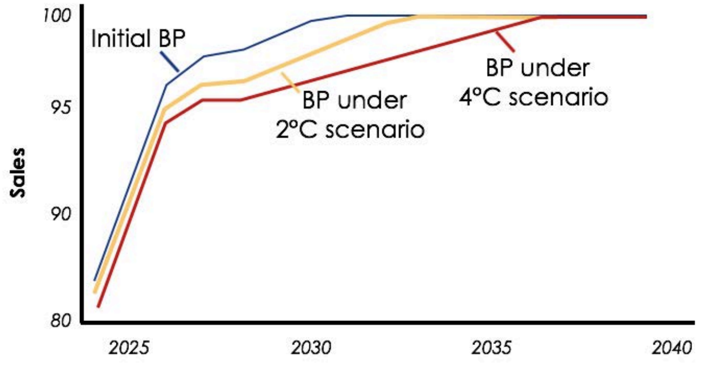


Figure 9 The impact of climate change on the sales can be used to challenge the business plans of the utility company. In this theoretical example, the achievement of the businesss plan (BP) objectives can be delayed by 3 to 7 years when accounting for climate change. (Source Carbone 4)

It is important to note that if this simple analysis provided quantified results for the impact of increasing temperatures on sales, **it does not constitute a complete climate risk assessment for the heating distribution network**. Many other impacts can be expected from climate change on the network (e.g. increasing supply costs, increasing operating costs, physical damages due to extreme events…). A thorough due diligence process would require to investigate all these impacts in detail.

Summary

This type of information can be used directly to challenge the business model of the heating utility and to assess the effect of climate change over its activities. However, it is important to note that we only quantified here one of the many impacts that climate change can have on the company. A thorough assessment is needed to estimate the other impacts than can occur (e.g. damages on the assets, increasing supply costs…)

4.3 Case study 3 – Climate risk assessment on a real estate portfolio

Physical climate risk for real estate depends on the building's vulnerability to climate hazards (elevation, land-use, local hydrology, insurance, building materials and design, age of the building) and on its exposure to climate hazards.
The level of detail and precision of the climate risk information is strongly linked to the level of detail of the asset's description (accurate location, detailed specificities…).

The analysis was carried out on **an aggregated portfolio from three French banks**, for three hazards that can have important structural and functional impacts on the buildings:

- **heatwaves** can lead to cracks in concrete structures, impact health and workers' productivity, and cause an increase in cooling costs.
- **intense rainfall** can lead to flooding that can cause damages to the structures, coatings and networks, as well as sanitary problems.
- **droughts**, especially impactful in clay-rich areas but that can also impact living conditions, through a decrease in the water resources.

Methodology

For this example, there is no readily-available impact function that links climate hazards and impacts. The idea here is to create ratings (from 1 to 10) describing climate hazards and vulnerability and to combine these ratings to obtain **a risk rating, for every asset in the portfolio and for every hazard** (figure 10).

Two climate indicators (step 1) were used for each climate hazard (e.g. the frequency of very hot days and the average maximum temperature for the heatwaves hazard). For each indicator, the values for every point in France, over the three time periods and two climate scenarios (+2°C and +4°C) were ranked to obtain a rating. This means that for each indicator, the points with the maximum/minimum value were given the highest/lowest ratings and that all other points in France were ranked according to this scale. For each hazard, final hazard ratings were obtained by averaging the two indicator ratings. At the end of this step, a **climate hazard rating** is obtained for every point in France, every time horizon, every scenario and every hazard (e.g. heatwave map on figure 11).

Potential physical and financial impacts (steps 2 and 3) were used to describe the asset's vulnerabilities to each climate hazard, following three main typologies: individual houses, collective housing and offices. Based on a literature review, the impacts of every hazard on every component of each type of building (e.g. roofs, structure, walls…) were listed and a vulnerability ranking was attributed based on the importance of the impact (lower values for impacts that need a small repair, higher values when the impact requires the expensive replacement of a component). Vulnerability ratings were averaged over technical components to obtain a total **vulnerability rating for each type of building and for each hazard**.
For each building and each hazard, the climate hazard ratings and the vulnerability ratings were averaged to create a **risk rating for each asset** in the portfolio (the numbers in the table on figure 11).

Finally, we aggregated the results at the portfolio level (considering the proportion of each asset in the portfolio value) to describe the **portfolio's exposure to each hazard** (step 4).

Figure 10 Impact chain for the real estate risk assessment

Figure 11 describes the type of results obtained for each asset in the portfolio: an exposure map for each hazard and a risk rating, for each asset, each time horizon and each scenario (here we show only +4°C scenario).

Map of exposure levels to heat in France in 2050

	Heatwaves			Intense rainfall			Droughts		
Asset	Ref	2035	2055	Ref	2035	2055	Ref	2035	2055
1	5	6	6	6	6	6	3	4	5
2	5	5	6	5	5	6	3	4	5
3	5	6	6	7	7	7	3	4	5
…	…	…	…	…	…	…	…	…	…
n	5	6	6	7	7	8	3	4	5

Table of risk rating sample for 3 hazards and 3 time horizons for a given portfolio

Figure 11 Exposure map of heat stress and location of the portfolio's constituents in 2050 (left) and risk rating sample for 3 hazards and 3 time horizons. These risks ratings correspond to a combination of hazard ratings and vulnerability ratings, for each hazard separately. These ratings will be aggregated a the portfolio level, weigthed by the importance of each asset in the portfolio.

Results

The aggregation at the portfolio enables to quantify, for each hazard, the proportion of the portfolio (in value) made of high-risk assets (i.e. "red flags", with a risk rating of 8/10 or more – this threshold is arbitrary here and used for illustrative purposes). This categorisation provides information on the potential financial impacts (e.g. impact on the credit risk, on the loan strategy…).

In this example, **the proportion of the portfolio highly exposed to intense rainfall increases from 4% in the reference period to 29% in 2050 (under +4°C scenario).** The proportion of highly exposed assets to **heatwaves** and **droughts** is still low in this example, but all the portfolio assets are subject to an increase in their risk ratings, which will lead to a **large number of red flags in the second part of the century**.

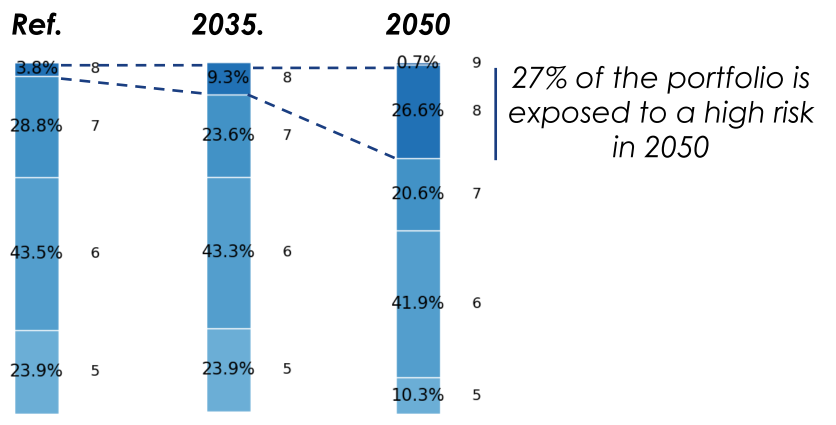


Figure 11 Distribution of risk ratings in the real estate portfolio towards intense rainfall

Summary

This example presents two types of information: first, it provides a broad view of the portfolio's exposure to climate risk in a national or regional context and second, it highlights the most-at-risk assets on which an enhanced risk analysis can be carried out. **This is useful for the daily management of new inputs to the portfolio as well as for the long-term strategy of investment, and risk or sustainability reporting. This methodology can also be used to assess risk on investment flows at early stage as few information is needed on the asset**.

4.4 Case study 4 – Climate risk assessment on a multi-sector portfolio

This analysis is similar to the case study described before but it looks at **an international equity portfolio** (131 constituents from diverse sectors). This main difference is that the vulnerability ratings were not calculated for buildings typologies but for economic sectors, as detailed in the methodology description below.

Methodology

As in the previous example, no impact function is available to link climate hazards and impacts for a large variety of economic sectors. We used again ratings describing climate hazards and vulnerability and combine these ratings to obtain a risk rating, for every company in the portfolio (figure 12).

The calculation of the climate hazard ratings is similar to what has been described in section 4.3, but it was applied for 7 climate hazards (increasing temperatures, heatwaves, changing rainfall patterns, rainfall extremes, storms, drought and sea level rise) across the whole world. At the end of this step, a **climate hazard rating** is obtained for every country, every time horizon, every scenario and every hazard.

Based on a large literature review and risk experiences (Amelung et al., 2007; CDC Group, 2010; EEA, 2017; Gaia, 2018; Hirschet al., 2015; IEA, 2015; IPCC, 2014; Linnerud et al., 2011; MacAlpine and Porter, 2018; Mercer, 2015; The Global Food Security Program, 2015; Verisk Maplecroft, 2018) covering 15 vulnerability factors we listed the potential impacts of the selected climate hazards on the different sectors and the level of vulnerability of each of these sectors (step 2 and 3). This provided a first level of information on the sectors' vulnerability and highlighted commonalities across sectors that could be of interest. The number of available projects and studies gave us a first idea on the depth of knowledge and the state of the art for each couple sector/hazard. From this review, a simple **vulnerability rating** (high-medium-low) was attributed to each economic sector.

For each company, the risk rating was computed as follows:
- description of the company's geographical and sectoral breakdown (based on the distribution of revenues or assets, depending on the available information in publicly available reporting)
- for each country of activity: extraction of the climate hazard ratings for all 7 hazards
- for each sector of activity: extraction of the vulnerability ratings for all 7 hazards
- for each pair country/sector, averaging of the two ratings to create a risk rating for all 7 hazards
- aggregation at the company level based on the importance of every country/sector in the activity
- multi-hazard aggregation to create one single climate risk rating for the company. This final risk rating is a value from 1 to 99 and is categorized in a risk scale (lower: <20; moderate: 21 to 40; medium: 41 to 60; high: 61 to 80; very high: 81 to 99).

Finally, we aggregated the results at the portfolio level (considering the proportion of each company in the portfolio value) to describe the **portfolio's exposure** (step 4).

Figure 12 Impact chain for the inter-nation, multi-sector case study

Results

Figure 13 shows the results of a risk assessment run on an equity portfolio. This portfolio had 131 constituents covering various sectors of the economy. The risk ratings has been calculated for every company and then aggregated at the portfolio level. Figure 13 shows the distribution of risk categories within the portfolio in 2100, according to a +4°C scenario: almost the whole portfolio is exposed to either a moderate or a medium risk, with no company in the high and very high risk categories. An explanation to the relatively low exposure can be found in the large proportion of services-oriented companies within the portfolio, which are less vulnerable than capital-intensive, industrial assets (figure 13 – left).

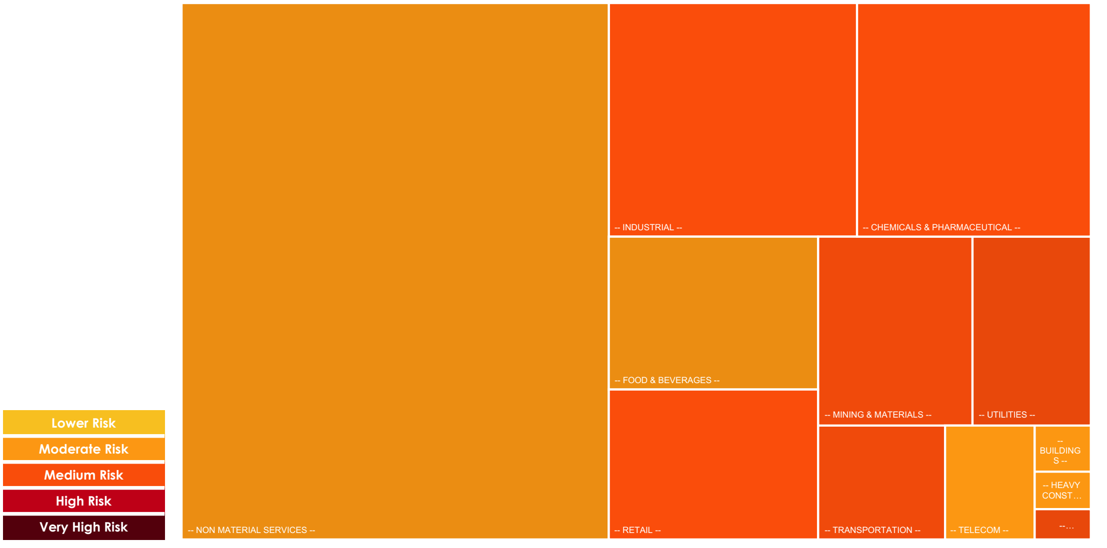


Figure 13 Distribution of risk ratings across sectors for the portfolio (2100, high emissions scenario, right). The size of the box corresponds to the relative value of each sector within the portfolio, whereas the color corresponds to the average level of risk. The five levels of risk are based on the aggregated risk ratings for each company in the portfolio, that is then aggregated at the sector level (lower: <20; moderate: 21 to 40; medium: 41 to 60; high: 61 to 80; very high: 81 to 99).

Going further, it is also possible to extract the portfolio's exposure to every hazard separately (based on an aggregation of the risk ratings of every company within the portfolio). Figure 14 is similar to figure 13 and shows the distribution of risk categories (from low to very high) in the portfolio, for every hazard. As in figure 13, the proportion is weigthed by the relative importance of each asset in the portfolio. **Sea level rise, storms and heatwaves are the most important hazards for the portfolio**, with respectively 15, 6 and 2% in the high risk categories (dark red, figure 14).

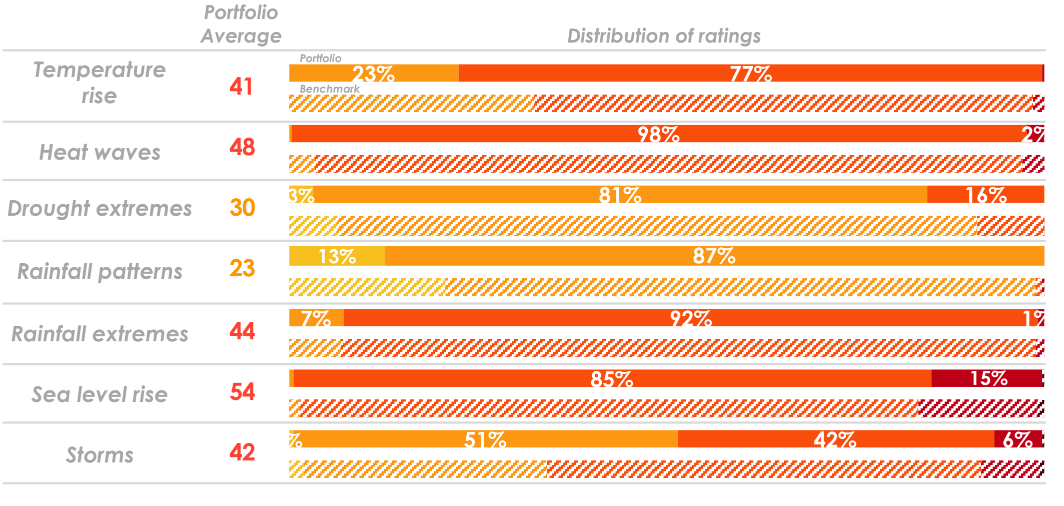


Figure 14 Distribution of risk ratings categories for each hazard and comparison with benchmark portfolio (2100, high emissions scenario). 15% of the portfolio is in the 'high-risk' category for sea level rise, whereas all the portfolio is in the two lowest categories for the hazard related to changes in the rainfall patterns. The benchmark portfolio includes a selection of 200 MSCI World constituents.

Due to the bottom-up process, it is also possible to extract the ratings corresponding to each hazard, each scenario and each time horizon for each asset. This information can be useful to **highlight the companies that are most-at-risk in the portfolio and to understand their vulnerabilities**. In this example, the highest risk ratings are obtained for utilities and transportation companies operating in Asia that are exposed to sea-level rise, storms, intense rainfall and to a lesser extent to heatwaves (not shown).

Summary

This type of analysis should be seen as **a broad, first order climate risk assessment**. If the the large proportion of services-related constituents in the portfolio is a reason for an overall moderate risk, a **thorough quantification of the risk of the exposure of most-at-risk companies would be useful to understand the physical and financial impacts on these companies**.

Going further

towards adaptation and resilience to physical climate risks

From a financial actor's point of view, physical climate risks can be managed the same way other risks are. Financial actors might want to divest away from risky assets, benchmark risk profiles across sectors, or engage with counterparties to reduce risks.

Divesting from risk might appear as a tempting strategy to minimise risks. However, in a finite and globalised world and a climate changing globally, every sector and activity will be impacted at one point. In order to minimise the risks, economic agents have to adapt to reduce vulnerability and exposure to climate change. In this context, financial actors might want to **engage with the entities composing their portfolio**, when possible, to improve adaptation and build resilience, hence minimising the risks on the activities and therefore of their investments. Below, we describe some measures that can be implemented at the counterparty's (or the asset's) level.

Note: Adapting to climate change has to go hand-in-hand with action on climate change mitigation in order to reduce the related hazards. A strong mitigation effort would be the most effective solution to minimise physical climate risks by reducing the hazards. Recent studies have found that mitigation costs could be offset by the avoided impacts in a world where global warming is limited to 2°C (e.g Orlov et al., 2020).

From a company's point of view, various actions can help reduce physical climate risks.

- **Physical measures** may include design adjustments that allow the project to be more resistant to more frequent or intense extreme events or structural improvements that adapt the infrastructure/asset to the changing climate.
- **Financial measures** may include extended insurance cover for new risks, but also an increase in the debt coverage ratio (DSCR) or the debt reserve account (DSRA), a lower leverage, higher pricing in case of cash flow variability (Acclimatise, Climate Finance Advisors and Four Twenty Seven, 2018). These measures may become less robust as risks become more and more important (for example, rising costs of insurance, or non-insurability of certain areas).
- **Soft measures** can also be implemented to improve governance (e.g. creation of a climate committee for a multi-country program), reporting (identification of indicators to be regularly updated, e.g. number of climate-related incidents) or risk management behaviours or policies (e.g. increase in control visits).

When identifying and selecting adaptation options, one should consider that some adaptation actions perform better in the context of uncertainty (from *EU Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient*):

- **no-regret measures**: these are measures that are worthwhile now (i.e. they allow to obtain net socio-economic results that exceed their costs) and remain valid whatever the future climate (e.g. insulating a building will reduce its vulnerability to temperature extremes as well as reducing A/C and heating costs).
- **flexible or adaptive measures**: they imply the implementation of incremental adaptation steps rather than an adaptation plan implemented on a large scale at a high cost at one time. This means that measures must be designed so that they make sense today, but at the same time they can change as more information becomes available. For example, delaying decisions while exploring and working with other stakeholders to find the most appropriate solutions can be a viable solution. This approach ensures that the appropriate level of resilience will be achieved within a reasonable time in the future. Keeping options flexible and open makes it possible to adjust them according to the systematic monitoring and evaluation of their performances.
- **robust measures**: these are adaptation measures based on a flexible approach that does not include a subsequent updating stage; the measures are efficient but not necessarily optimal.
- **win-win measures**: these are measures that have the expected results in terms of minimizing climate risks or exploiting potential opportunities, but which also have other social, economic or environmental benefits; these may be measures introduced mainly for reasons other than climate change, but which offer the expected adaptation benefits. For example, this could be the introduction of measures to improve water efficiency in agriculture, industry or buildings.

If an engagement with the entities in the portfolio is possible and/or required, some guiding questions to start the discussion have been proposed, such as the following examples extracted from the World Bank Climate screening tools:

On the exposure to climate hazards:

- What have been the historical trends in temperature, precipitation and drought conditions?
- How are these trends projected to change in the future in terms of intensity, frequency and duration?
- Has the location experienced acute hazards such as strong winds, sea level rise, storm surges, heatwaves in the past that may occur again in the future?

On vulnerability and adaptive capacity:

- Can climate hazards impact the population (loss of lives, injuries, public health impacts, material and economic loss), infrastructure (physical damage to assets and disrupted service), or economy (changes in GDP, exports, imports, and tourism)?
- Does the project design take into account recent trends and future projected changes in identified hazards?
- Does the project design consider how the structural integrity, materials, siting, longevity and overall effectiveness of urban infrastructure, if applicable, may be impacted?
- In particular, does the design “lock in” certain decisions for the future?

Guiding questions for the investors are also available in the ClimINVEST hazard-focused factsheets.

Appendices.

A. Appendix 1: How to assess sectoral vulnerability?

A detailed assessment of sectoral climate vulnerability is required in order to analyse the related climate risks. Based on a large literature review, Carbone 4 listed the potential **impacts** of the selected climate hazards on the different sectors. This provided a first level of information on the sectors' vulnerability and highlighted **commonalities across sectors** that could be of interest for the case studies. The number of available projects and studies provided a first idea on the depth of knowledge and the state of the art for each couple sector/hazard.

To highlight this process, we present here the results of the vulnerability assessment for two sectors (and corresponding sub-sectors):

- the Retail sector (with its perishable products sub-sector)
- the Mining sector (Special mining & materials)

The table below summarises the vulnerability information for these two sectors. The final level of vulnerability are the results of the described literature review.

See Annex 1 for a non-exhaustive list of sector-specific impacts.

	RETAIL Perishable products	**MINING & MATERIALS** Special mining
Increase in average temperature	High	Medium
Changes in the intensity or frequency of cold spells	High	High
Changes in the intensity or frequency of heatwaves	High	Medium
Changes in drought extremes	Medium	High
Changes in rainfall patterns	High	Medium
Changes in rainfall extremes	Low	High
Sea level rise	Low	High
Changes in the intensity or frequency of storms	Low	High

The level of vulnerabilities depends mainly on the potential impacts on the activities and on its supply chain.

In this example, **the retail of perishable products** relies heavily on temperature stability. It is dependent on the availability of electricity for refrigeration and vulnerable to high temperatures that can impact the products and increase operating costs for refrigeration. The importance of the upstream supply chain is high, but the sector can adapt to droughts in one region and reorient its supply chain if needed, which makes it less vulnerable to droughts than farming. Even though sea level rise and storms can impact stores and warehouses, the activity is not linked to a given location. This means that the retail sector can follow the customers' displacements that can occur because of sea level rise in coastal zones, for example.

The mining sector is a heavy industry, locked into pre-determined locations. It involves large capital-intensive assets that cannot be displaced and is therefore highly vulnerable to extreme events such as storms and sea level rise. Overall, this sector is vulnerable because of its geographical concentration, its capital intensity and the large investments that are required and that need to be made profitable for a long period of time. The importance of water in mineral processing and the physical intensity of the work makes the sector vulnerable to droughts and heatwaves.

This type of vulnerability assessment was used in the case study on the listed investment portfolio and is useful for a broad risk screening when detailed impact functions are not available.

B. Appendix 2: Example of physical impacts coming from 12 climate hazards on 4 sectors: Agriculture, Energy, Tourism and Buildings (Source: Carbone 4 based on multiple sources)

	Hazard	Type of Hazard	Agriculture	Energy	Tourism	Buildings
1	Increase in average temperature	Chronic	Increased occurrence of animal and plants' diseases Decreased yields for most crops (in current location) Impact on workers' health and productivity	Transport disruption in arctic regions (oil&gas) Decreased efficiency for thermal and nuclear plants Shutdown of thermal and nuclear plants to avoid increase in river temperature Changes in PV yield	Impact on environment that lead to lower frequentation (snow…)	Impact on workers' health and productivity
2	Changes in the water temperature	Chronic		Impact on thermal and nuclar plants cooling		
3	Changes in the int or freq of cold spells	Acute	Season failures (e.g. for new crops not adapted to frost)			
4	Changes in the int or freq of heatwaves	Acute	Damage (potentially lethal) to crops	Increase in peak demand that could lead to system failure Decreased efficiency for thermal and nuclear plants	Change in attractivity	Impact on workers' health and productivity Increased number of non-working days
5	Changes in drought extremes	Acute	Significant impact of drought - season failures, reduced yield Increased incidence of forest fires	All energy sectors exposed to water scarcity risks (varying degrees) Water shortage for hydroelectricity production and cooling of thermal/nuclear Disruption of O&G transport during low flows	Water use restriction	Water use restriction
6	Changes in rainfall patterns	Chronic	Heavy susceptibility to changes in rainfall patterns - changes in yield, crops no longer adapted	Water shortage for hydroelectricity production and cooling of thermal/nuclear	Change in attractivity	
7	Changes in rainfall extremes	Acute	Damages to process, storage and transportation infrastructures	Operation disruptions (esp fossil fuels because often coastal) Damages on oil&gas transport infra	Transport disruption due to more frequent floods	Interruption to provision of utilities (power, water, waste) due to extreme weather events Increased costs for flood protection Decreased activity following extreme events due to workers and customers inability to to reach commercial centre
8	Sea level rise	Chronic	Saltwater intrusion	Operation disruptions (esp fossil fuels because often coastal)	Physical impact on assets Transport disruption due to more frequent floods Change in attractivity for coastal zones	Impact on assets and occupancy rates (efficiency and location discount) Risk of insurance market disruption
9	Changes in the average relative humidity	Chronic	Impact on crop storage after season	Reduced cooling efficiency	Change in attractivity (coastal areas)	
10	Changes in the average solar radiation	Chronic		Changes in PV yield		
11	Changes in the average windspeed	Chronic		Impact on cooling efficiency Increased exposure to saltwater leading to corosion Changes in wind power yield		Increased impact on buildings structures (corrosion…)
12	Changes in the int or freq of storms	Acute	Saltwater intrusion Damages to perenial cultures and forests	Damages on oil&gas transport infra Damages to electricity transmission towers and lines	Physical impact on assets	Impact on assets and occupancy rates (efficiency and location discount) Physical impact on assets due tu extreme events

C. Appendix 3: Example of climate indicators to be used in the assessment of physical risks on 4 sectors: Agriculture, Energy, Tourism and Buildings (Source: Carbone 4, Météo France and CICERO)

Based on a large literature review (peer-reviewed articles, science projects reports, private sector), climate variables and indicators were listed for each sector [Note: the terms *variables* and *indicators* are used here as defined as follows: variables represent information extracted directly from climate data (e.g. minimum temperature, precipitation, wind speed) whereas indicators are computed by processing variables to obtain information on the **frequency** (e.g. number of warm nights), **intensity** (e.g. maximum 5-day precipitation) or **duration** (e.g. length of longest dry spell) of climate processes].

Indicators were linked to the variable(s) of interest in order to assess the data quality and availability for a given location and time horizons (see below). Each indicator is associated with at least one direct hazard and, if relevant, with an indirect hazard.

Sector	Activity	Impacts	Variable	Indicators	Financial impacts	Vulnerability
Agriculture	Crops	Temperature and precipitation change on production	T, rainfall	Average T, rainfall Length of growing season	Revenues decrease	High
		Impact of extreme events (drought, flood)	Rainfall, humidity	SPI Number of heavy precip days / contribution from wet days	Damage to properties Revenues decrease	High
		Impact on soil erosion	T, rainfall	Width of soil lost	Revenues decrease	High
	Livestock	Temperature and precipitation change on cattle food	T, rainfall		Revenues decrease	High
		Impact on disease	T, humidity	Frequency of events where T and humidity > given threshold	Revenues decrease	High
	Wood	Impact of precip on activities (snow, frost, heavy rainfall)	T, rainfall	Number of heavy precip days Number of freezing days Number of snow days	Shutdown of activity	Medium
Energy	Energy demand	Changes in energy demand	T	Heating degree days Cooling degree days		Medium
	Hydropower	Changes in water availability	T, rainfall	Available streamflow Average rainfall Snow melting Contribution of heavy precip	Shutdown of activity	High
	Thermal/Nuclear	Impact on efficiency	T	Tmax?	Revenues decrease	High
		Shutdown due to T	T	Tmax?	Shutdown of activity	Medium
	Solar	Impact on production	Radiation	Averaged solar radiation		Medium
	Wind	Changes in wind patterns and extremes	Wind	Wind distribution	Revenues decrease Shutdown of activity	Medium

Health	Individual	Impact on human health	T, humidity	Wet bulb T Number of warm nights Frequency and intensity of heatwaves	Increases in expenses	High
	Services	Impact on health services and infrastructures	T, humidity	Wet bulb T Number of warm nights Frequency and intensity of heatwaves	System failure	Medium
Construction	Activity	Impact on activity (non working days)	T, rainfall	Length of building season Number of freezing days Number of heavy rainfall days	Shutdown of activity Delays expenses	Medium
		Impact on workers' health and efficiency	T, humidity	Wet bulb T	Shutdown of activity Delays expenses	Medium
Industrial	Activity	Changes in water availability	T, rainfall	Available streamflow Average rainfall	Shutdown of activity	High
		Impact on workers' health and efficiency	T, humidity	Wet bulb T	Shutdown of activity Revenues decrease	Medium
		Changes in energy availability and prices	T, rainfall		Shutdown of activity	Medium
	Infrastructures	Impact of floods	Rainfall	Number of heavy rain days	Activity delayed Loss of property	High
		Impact of storms	Rainfall, wind	Frequency of extremes (wind/storms...)	Activity delayed Loss of property	High
	Supply chain	Impact of extreme events on supply of goods	T, rainfall	Frequency of extreme events (droughts, floods, cyclones...) Sea level rise	Shutdown of activity Delays expenses Revenues decrease	Medium
Tourism	Summer	Impact on frequentation	T, rainfall, humidity	Tourism climate index	Revenues changes	High
	Winter	Impact on frequentation	T, snow	Snow accumulation, number of sunny days	Revenues changes	High
Buildings	Energy consumption	Changes in energy demand	T	Heating degree days Cooling degree days	Increases in expenses	High
	Building resilience and value	Impact of extreme events	T, rainfall, wind	Frequency of extremes (wind/storms, floods...)	Value decrease Loss of property	High
		Impact of sea level rise	Sea level rise	SLR	Value decrease Loss of property	Medium
Transports	Activity	Ice on road	T	Number of frost/freezing days	Activity delayed	Medium
	Infrastructures	Impact of floods	Rainfall	Number of heavy rain days	Activity delayed Loss of property	High
		Impact of storms	Rainfall, wind	Frequency of extremes (wind/storms...)	Activity delayed Loss of property	High
Retail	Sales	Changes in seasonal temperature	T	Seasonal average T	Revenues changes	Medium
Water	Water demand	Increase in demand due to T	T, humidity	Wet bulb T Number of warm days/nights Frequency and intensity of heatwaves Frequency and intensity of droughts		Medium
	Water resources	Changes in T and rainfall	T, rainfall	Tmax, precipitation Contribution of heavy rainfall		High

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