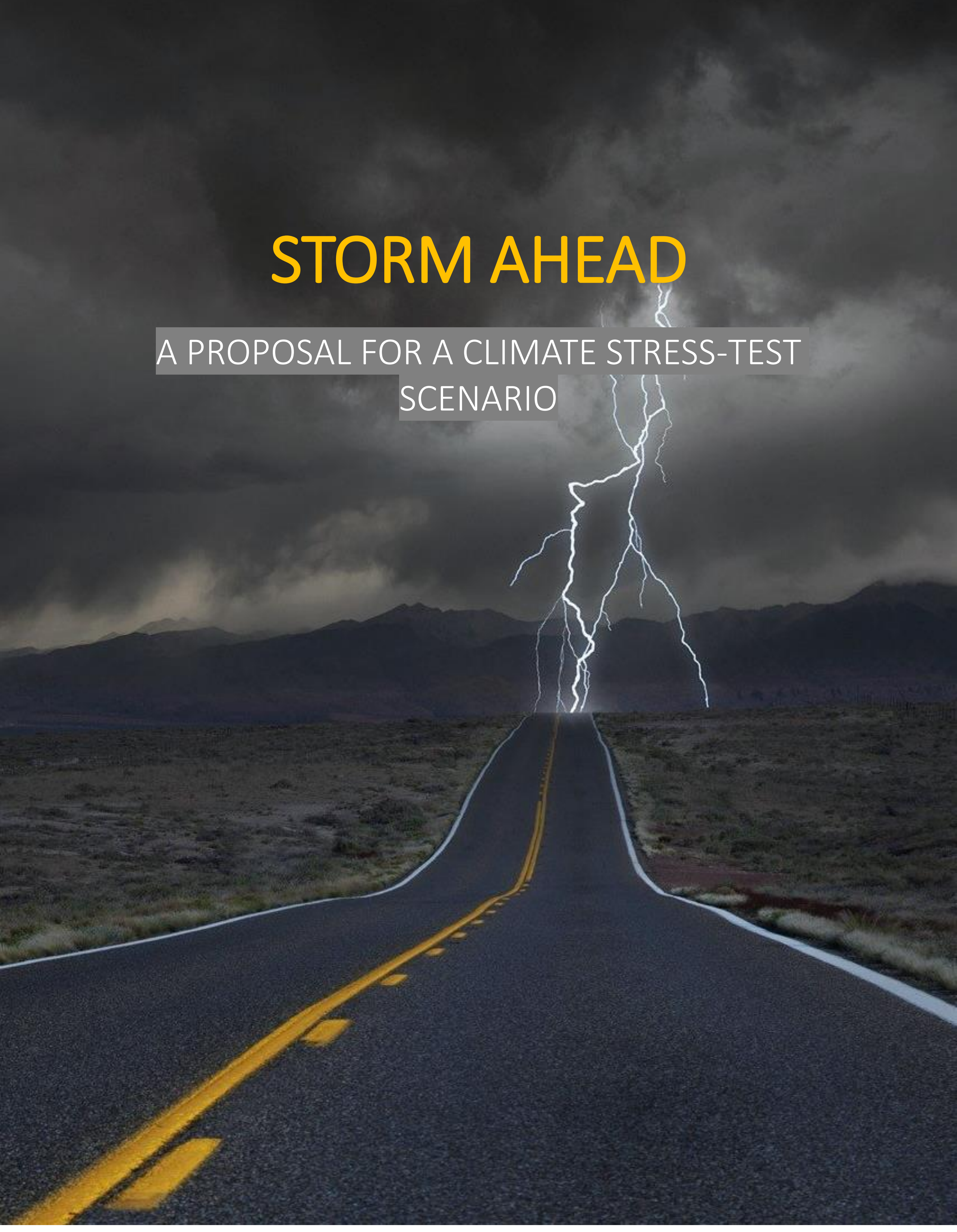


STORM AHEAD

A PROPOSAL FOR A CLIMATE STRESS-TEST SCENARIO

2° Investing Initiative

DISCUSSION PAPER
April 2019

ABOUT THE PAPER AND THE AUTHORS

2° Investing Initiative (2°II) is a non-for-profit think-tank working to integrate long-term risks and societal goals into financial markets. With offices in Paris, London, Berlin and New York, the Initiative engages a global network of over 50 partners and members, including financial institutions, investment researchers, asset managers, policymakers, research institutions, academics and NGOS. Our work primarily focuses on three pillars of finance – metrics and tools, investment processes, and financial regulation.

THE AUTHORS: This paper has been written by Soline Ralite and Jakob Thomä, from the 2°Investing Initiative.

THIS PAPER: This report provides guidelines to build an adverse climate scenario that can be used by financial supervisors as inputs into either traditional or climate-specific stress-tests of regulated entities. The report has been designed to cover the key metrics and indicators found in traditional stress-tests, integrating both risks associated with the transition to a low-carbon economy as well as physical risks in a +4°C / +6°C world. The report provides both insights into key indicators needed in the context of climate stress-tests or scenario analysis, the values they would take in the context of transition risk and physical risk analysis based on the existing literature, options for modelling these indicators moving forward, and example applications developed by the 2° Investing Initiative.

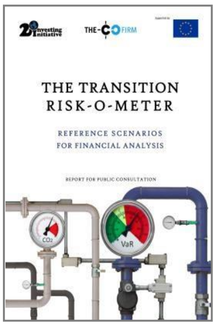
OUR RELATED PUBLICATIONS

OTHER PUBLICATIONS RELATED TO CLIMATE RISKS ANALYSIS

CHANGING COLORS

ADAPTIVE CAPACITY OF COMPANIES IN THE CONTEXT OF A TRANSITION TO A LOW CARBON ECONOMY

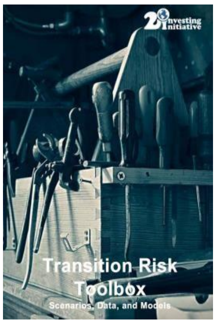
How to assess the adaptive capacity of companies that face long- term risks like the energy transition?



THE TRANSITION RISK-O-METER

REFERENCE SCENARIOS FOR FINANCIAL ANALYSIS

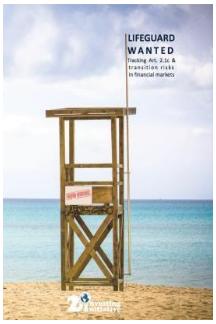
Translation of energy transition scenarios into “risk parameters” for integration into DCF models



Transition Risk Toolbox

Scenarios, Data, and Models

Mapping of methodological options, practical tools & data for integrating climate-related risk factors into financial analysis



LIFEGUARD WANTED

Options for monitoring Art. 2.1c of the Paris Agreement & transition risks

Upcoming – Physical risks & fixed income

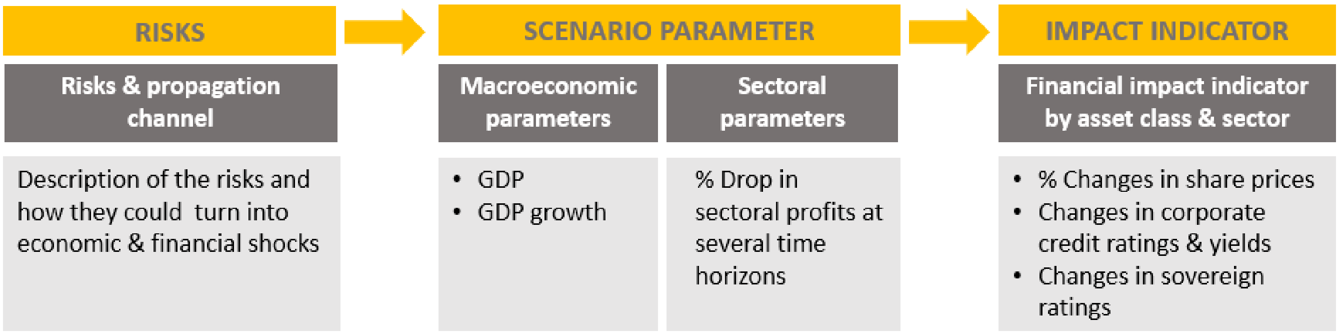
TABLE OF CONTENT

READERS GUIDE

This report provides guidelines to build an adverse climate scenario that can be used by financial supervisors as inputs into either traditional or climate-specific stress-tests of regulated entities. The report has been designed to cover the key metrics and indicators found in traditional stress-tests, integrating both risks associated with the transition to a low-carbon economy as well as physical risks in a +4°C / +6°C world.

The metrics and indicators covered in this report are displayed on Figure 0.1. It has to be noted that unlike traditional stress-tests, unemployment and inflation data couldn't be provided, as none is available under either an abrupt transition scenario or no mitigation scenario. As for sectoral parameters, instead of displaying selected prices (e.g. oil, real-estate, etc.), we provide changes in profits for companies in key sectors (See the introduction for more details).

Figure 0.1 *Stress-testing framework & indicators displayed*



For each indicator displayed, e.g. share prices on the sample page on the right, we:

- qualitatively describe how the risks can affect the indicator;
- provide a review of literature on the issue;
- explain how supervisors could estimate the indicator under the risk scenario;
- provide an example of what these estimates could look like

TRANSITION RISKS **IMPACT ON SHARE PRICES**

HOW DO THE RISKS MANIFEST?

As explained above, climate change will impact companies' revenues and charges in many ways, with the amplitude of the effect varying depending on the sector they operate in. These changes in the companies' balance sheets will then impact their market value, as the demand for shares issued by weaken companies will decrease.

EXISTING LITERATURE ON THE ISSUE

To date, little research has been conducted to estimate the impact of transition risks on share prices, and none when it comes to a delayed action scenario. Among the existing literature, two main approaches can be identified:

Table 1.3 *Main approaches used by studies to estimate the impact of transition risks on share prices*

	TOP-DOWN approach	BOTTOM-UP approach
CORE PRINCIPLE	**Step 1:** Using an econometric model to simulate macroeconomic variables, among which are global share prices, under a transition scenario **Step 2:** Distribute the global change in equity value among economic sectors according to sector-specific weights	**Step 1:** Estimate, for each sector, the impact of the transition on revenues & costs, and assess the adaptative capacity of each industry **Step 2:** Use a valuation model to estimate the impact of these changes in revenues & costs on share prices
EXAMPLE	*CISL "Unhedgeable risks" (2015), DNB "An energy transition risk stress-test for the financial system of the Netherlands" (2018)*	*Ecofys/Navigant "Climate risks of 3 funds of Actiam" (2018), Carbon Delta VaR methodology, ET-Risks*

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

To estimate the impact of a "too late, too sudden" transition on share prices, supervisors could adopt either one of the two approaches, as long as the shocks resulting from a sudden decision are accurately represented. We however recommend the bottom-up approach as, for now, no macroeconomic model accurately modelling an abrupt transition exists.

OUR TAKE ON THE ISSUE

Based on our estimates of sectoral revenues, we ran a DCF (Discounted Cash-Flow) model to estimate the NPV (Net Present Value) of future cash-flows, starting in 2025. In line with Gordon's formulation of future dividends' flows (Gordon 1959), and assuming that dividends are proportionate to cash-flow, the difference in share prices between the "business as usual" and the transition scenarios is assumed to equate the difference in NPVs. A world average of our regional results is displayed in Figure 1.5 below. See Annex 2 for more details on the methodology used.

Figure 1.5 *Expected impact on share prices compared to baseline for "smooth" & "too late, too sudden" transition scenarios for key sectors, assuming a sudden repricing in 2025 (%) – World average*

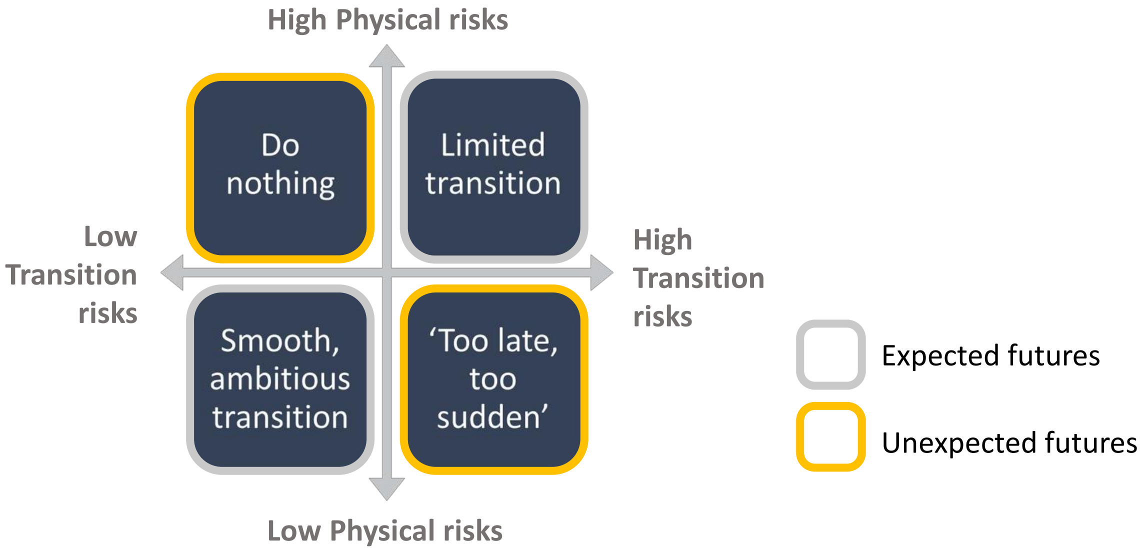
13

SETTING THE SCENE: CLIMATE RISKS & STRESS-TESTING

Climate risks are the risks posed to the financial sector by climate change itself (physical risks) and by our collective efforts to mitigate these (transition risks). These risks vary depending on the climate scenario considered. Figure 0.2 illustrates this idea: Depending on the depth of the mitigation efforts made, either the physical risks or transition risks prevail.

As the notion of climate risks becomes mainstream, so does the demand of financial institutions to quantify their potential impact. Broadly, two types of analysis can be conducted to do so: either (1) *"assessing the expected"*, i.e. exploring the extent to which asset prices accurately reflect the *expected* impact of climate change and the energy transition; or (2) *"stressing the unexpected"*, i.e. assessing the resilience of assets to potential *unexpected*, but highly material tail events – yellow scenarios on Figure 0.1. This latter objective is more likely to be pursued by financial regulators, and stress-tests may be a tool to answer to this demand – although they may need to be adjusted, as highlighted on the next page.

Figure 0.2 *Possible climate futures and associated risks*



To date, no comprehensive regulatory stress-test assessing both transition and physical risks exists, as most of the existing work focuses on companies and individual financial institutions. Yet, there are some notable examples of a growing interest for regulatory climate stress-testing:

- **Dutch Central Bank**: A first report assessing the potential impact of floods on credit losses, as well as quantifying the exposure of Dutch financial institutions to transition risks has been published in 2017 ("Waterproof? An exploration of climate-related risks for the Dutch financial sector"). It was followed by another, more in depth analysis of transition risks and their impact on FI's expected losses: "An energy transition risk stress test for the financial system of the Netherlands" (2018).
- **Bank of England**: The Bank of England is planning to include the impact of climate change in its UK bank stress tests in 2019. Previously, it has conducted analysis on its insurance companies.
- **Battiston & Monasterolo** published in 2019 a stress-testing methodology aiming at pricing transition risks in today's value of equity and corporate bonds in the energy & power sector, as well as in sovereign bonds' value (*"A carbon risk assessment of central banks' portfolios under 2° aligned climate scenarios"*, 2019), that they applied to the sovereign bond portfolios of the **Central Bank of Austria**.

INTRODUCTION

WHAT COULD A REGULATORY CLIMATE STRESS-TEST LOOK LIKE?

As highlighted in our “Right direction, wrong equipment” report (2017), climate risks do not fit well into the traditional regulatory stress-testing frameworks. Both the long-term horizon and sectoral specificity of those risks mismatch the 3-years time frame and aggregated indicators of traditional stress-tests. Yet, we believe that applying some minor changes to the classical framework (i.e. extending the time frame to 5 years and adding a few sectoral indicators), and choosing appropriate transition & climate change scenarios could solve these problems:

SOLVING THE TIME HORIZON ISSUE

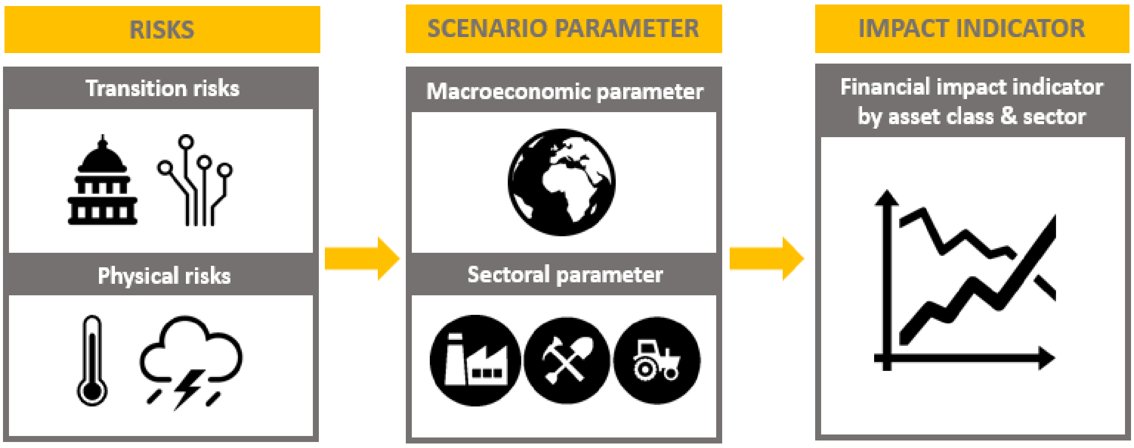
- For transition risks, using a “too late, too sudden” scenario based on the premise, coined by UN PRI and the ESRB, of the “Inevitable Policy Response”, allows the assessment of a “sentiment shock” occurring in 2025, and therefore provides for a stress-test with a more long-term time horizon. See page 8 for more details.
- For physical risks, a “shock” scenario, assessing the impact of major weather events, could be applied at any time horizon. See page 19 for more details. However, since this approach omits all the incremental effects of climate change, we therefore developed a second, more “long-term” scenario to assess their materiality. Integrating these more long-term trends however by design remains an incomplete exercise.

SOLVING THE GRANULARITY ISSUE

Figure 0.3 illustrates the current stress-testing framework. First, scenario parameters are displayed, both macroeconomic ones (e.g. GDP) and sectoral or sub-sectoral ones (e.g. real estate prices, oil prices). Some aggregated impact indicators are then provided, such as global share prices or credit spread. In our analysis, we replaced the sectoral scenario parameters with the mean changes in profits for exposed sectors (e.g. for transition risks: mining, utilities), as providing all the relevant prices & production indicators would be too granular for the classical framework, and disaggregated the impact indicators by sector (e.g. changes in share prices, corporate and sovereign credit ratings by key sector).

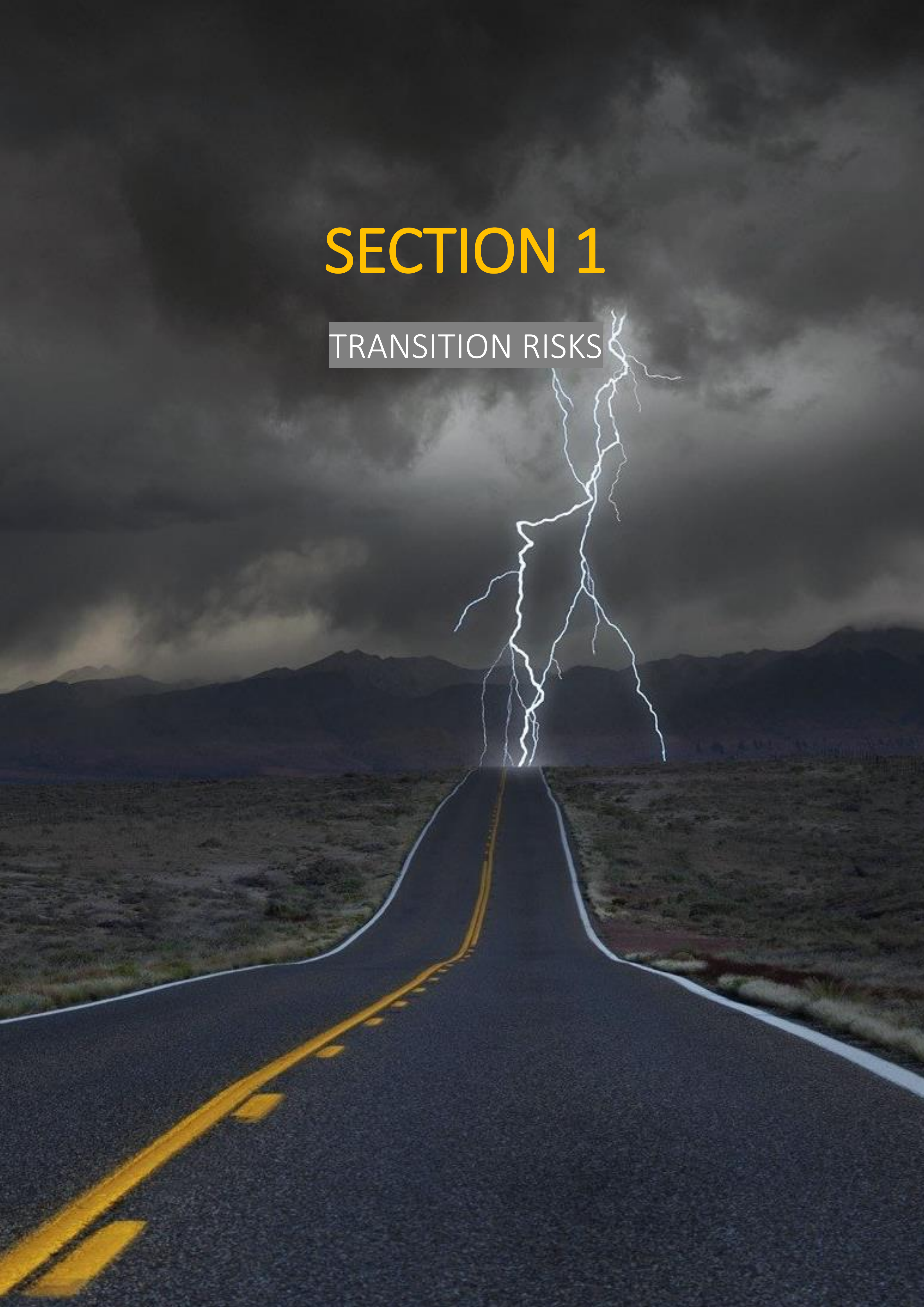
While the solutions identified here provide some means of addressing the mismatch between traditional stress-testing frameworks and climate risks, challenges remain. The focus of this paper is to identify and develop a ‘strawman’ stress-testing scenario. Beyond the scope of this paper, but requiring broader discussion and analysis, are new tools and approaches to thinking about the interface of climate risks and financial supervision, like those pioneered in California and Switzerland by the State Secretariat of Financial Affairs.

Figure 0.3 *A stress-testing framework*



SECTION 1

TRANSITION RISKS



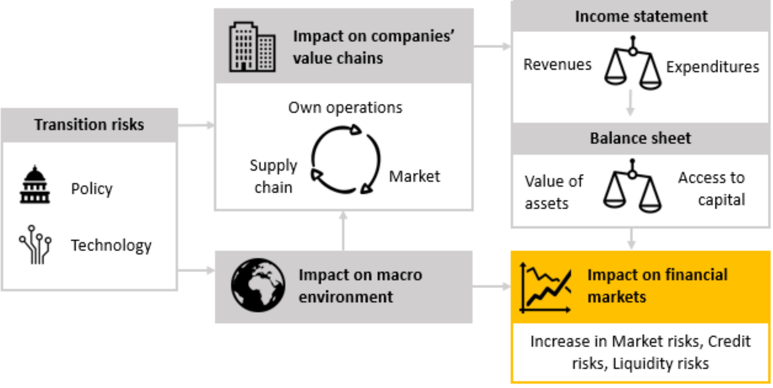
WHAT ARE TRANSITION RISKS AND HOW DO THEY MANIFEST?

Transition risks are the risks posed to the financial sector by a low-carbon transition. These risks include:

- **Policy risks**: Policies aiming at decreasing GHG emissions in order to not exceed the 2°C target by the end of the century, such as carbon prices, threaten the viability of carbon-intensive industries and related financial assets.
- **Technology risks**: Beyond policy risks, there is uncertainty in technological development and deployment, which can represent both opportunities and risks for companies in exposed sectors. Technology trends may be amplified by policy incentives.
- **Legal risks:** Legal risks may arise as a function of climate litigation, for example in the context of climate damages (Minter Ellison & 2°II, 2017). Given their unique nature, they are not further explored in this stress-test framework, may however be considered moving forward.

Transition risks are characterized by **their sectoral specificity** and **long-term nature**. Hence, while some sub-sectors might benefit from the transition (e.g. renewable energies, electric vehicles), or be left unaffected, some will be strongly hit (e.g. mining, ICE vehicles,…).

Figure 1.1 *Propagation channel of transition risks to the real economy and the financial sector*



EXISITING WORK ON THE ISSUE: ASSESSING THE EXPECTED VS STRESSING THE UNEXPECTED

Driven by a growing body of evidence that transition risks may create value destruction for key industrial sectors that are prominently represented in financial markets (e.g. energy, utilities), financial supervisory authorities, investment firms and consultancies are starting to assess the potential impact of a transition on the financial sector. Table 1.1 summarizes the main existing initiatives and the asset classes they cover. Most of these studies assess the impact of a "likely" transition, while little to no work as been done to "stress the unexpected", i.e. analyze the consequences of a "worse-case" transition on financial stability.

Table 1.1 *Main studies estimating the exposure of the financial sector to transition risks (in grey = covered asset classes)*

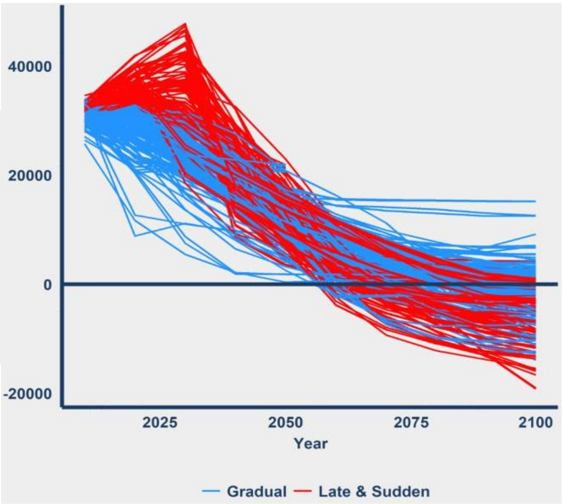
Asset-class/sector level	National financial sector level	Issuer/portfolio level
"Unhedgeable risk", CISL (2015) - *Equity, bonds (sovereign & corporate), commodities*	"An energy transition risk stress test for the financial system of the Netherlands", DNB (2018) - *Equity & corporate bonds*	"A carbon risk assessment of central banks' portfolios under 2°C aligned climate scenarios", S. Battiston, I.Monasterolo - *Equity, bonds (sovereign & corporate)*
"Investing in a time of climate change", Mercer (2015) - *Equity, bonds (sovereign & corporate), commodities*	"Operator Carbon Risk Tool" developed by Ecofys for the German government - *Corporate loans*	ET Risks' reports on sectoral impacts of transition risks (2018) - *Equity*
"Heat map shows wide variations in credit impact across sectors", Moody's (2015) - *Rated dept*		"Extending our Horizons", UNEP FI (2018) - *Corporate loans*
		Company-level VaR (e.g. furnished by Ecofys, Carbon Delta, etc.) - *Equity*

WHICH TRANSITION SCENARIO TO CHOOSE FOR A STRESS-TESTING EXERCISE?

Many uncertainties remain as to the form that a low-carbon transition would take. The ESRB scientific advisory board's report *"Too Late, too sudden?"* (2016) identified two types of scenario outcomes, a 'gradual', smooth ambitious scenario and a late & sudden one. This concept has been further developed by the UN PRI in 2018 operating under the premise of an "Inevitable Policy Response".

Figure 1.2 below shows the two types of categories as exemplified in a broad sample of IPCC scenarios filtered by ambition that can be linked to a 50% or higher probability of limiting global warming to 2°C above pre-industrial levels. In addition to the two more ambitious scenarios, transition outcomes could also of course involve a 'do nothing' approach or a limited climate transition ambition. This latter possibility will be analyzed in the second part of this report, dedicated to physical risks.

Figure 1.2 *2° aligned scenario outcomes in the IPCC scenario database*



(Source: Authors, based on IPCC 2013)

Considering that the purpose of a stress-testing exercise is to assess the impact of a "worst-case" scenario on the financial system, a **"too late, too sudden" scenario, assuming a "Climate Minsky" moment by 2025**, is more suited than a "smooth transition" one. This approach also allows to assume a "sentiment" shock by the moment climate action is taken, leading to a sudden repricing of financial assets.

However, such a "delayed action" scenario hasn't yet been explored by macroeconomic or energy-economy models, and few information is therefore available to quantify its economic implications. Building on IEA's B2DS (Beyond 2°) & OECD's "delayed action" scenarios, the following pages aim at bridging this gap by providing a methodology to estimate the impact of such a trajectory on GDP, sectoral profits, and financial assets (equity, corporate, and sovereign bonds).

HOW DO THE RISKS MANIFEST?

For a delayed transition to reach the same emissions target at the end of the century than an early one, significantly more stringent policies would be needed, with several implications: On the supply side, the buildup, before the transition starts, of capital stock dedicated to carbon-intensive production patterns leads to a significant amount of stranded assets once the transition is underway (USD 310 billion in the upstream oil sector alone - IEA estimates), and the need to quickly adapt to stringent climate policies drives high R&D and capital expenditures. On the demand side, the sharp increase in fuel and power prices significantly cuts households' purchasing power. Both these supply and demand impacts ultimately affects short-term GDP growth.

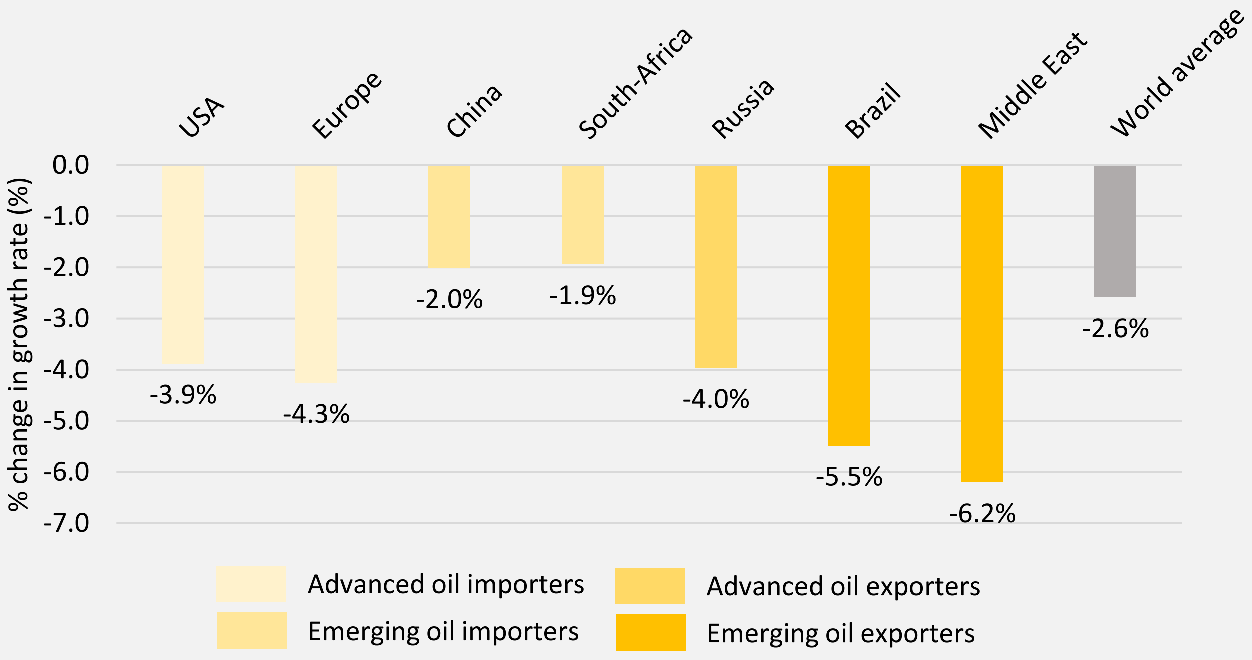
EXISTING LITERATURE ON THE GDP IMPLICATIONS OF AN ABRUPT TRANSITION

To date, little research has been conducted to estimate the impact of a delayed action scenario on GDP. Most of the research efforts regarding such a scenario have focused on measuring the additional mitigation costs it would bring about (Jakob et al., 2011; Furman et al., 2015). Estimates range **between 40 to 50% increase in global abatement costs**, mainly due to the buildup of capital stock dedicated to carbon-intensive production patterns which become stranded once the transition is underway. The only study quantifying the drop in GDP resulting from a delayed climate action is, to our knowledge, OECD's 2017 "Investing in Climate, Investing in growth" report. **Their focus is however restricted to the GDP impact of upstream oil stranded assets.**

OUR TAKE ON THE ISSUE

Using OECD's estimates of the GDP implications of delayed climate action, crossed with IEA's growth projections for several world regions (WOE 2018), we derived the following figures:

Figure 1.3 *Growth rate shock one year after climate action has been taken (%)*



As expected, delaying the energy transition sharply impacts growth one year after action has been taken, with emerging fossil fuels exporters being the more strongly impacted. Ten years after, growth rates of most countries are back to their baseline level, except for oil exporters (-1.3% growth rate for emerging exporters, and -0.1% for advanced exporters).

HOW DO THE RISKS MANIFEST?

Transition risks, and particularly those stemming from a “too late, too sudden” transition, would impact carbon-intensive industries’ profits across the entire ‘profit value chain’:

$$\textit{Net profits} = \overset{4}{(\textit{Production volume x Prices})} - \overset{2}{\textit{Costs of Goods Sold}} - \overset{3}{\textit{OPex}} - \overset{1}{(\textit{Taxes + Interests})}$$

	Indicators needed to quantify the impact	Indicators needed to quantify the impact
1	**Increased cost of emitting CO2**: Under a transition scenario, the implementation of a carbon tax will cut the margin of carbon intensive industries proportionally to their emissions. Under a “too late, too sudden” scenario, carbon prices would need to be higher than under a “smooth” transition scenario, in order to foster a quick decrease in emissions.	- Production - Carbon intensity of production - Carbon tax
2	**Increased cost of production inputs**: During a low carbon transition, carbon intensive goods will increase in prices due to pass-through of direct emissions costs. Industries using such carbon intensive goods as production inputs will thus be impacted.	- Prices of production inputs
3	**Additional depreciation costs and R&D expenditures**: Under a transition scenario, significant capital expenditures in low-carbon technologies will increase companies’ annual depreciation costs (included in Operating Expenses). Under a “too late, too sudden” scenario, the depreciation costs of “brown” capital stocks build up before the transition starts add up to these green expenses. R&D expenditures will also likely increase.	- CAPEX - R&D expenditures - All other OPEX
4	**Changes in revenues**: Companies’ revenues will be affected through a change in prices and consumer demand: As they become increasingly costly to produce, prices of carbon intensive goods will likely increase, and consumers will, in turn, decrease their demand for such goods. A delayed transition, as it would increase the costs bared by carbon-intensive industries, would likely deepen this effect.	- Production - Prices

All these incentives will likely drive companies to adapt their business model and slowly replace carbon-intensive by low-carbon activities.

EXISTING LITERATURE ON SECTORAL IMPACT OF AN ABRUPT TRANSITION

A range of initiatives have already sought to quantify the sectoral impacts of a “smooth” energy transition, and provide some indicators allowing to quantify its impact on the profits’ determinants detailed above. Two relevant initiatives in this regard are the EU H2020-funded ET Risk project and UNEP FI’s working group on transition risks. To the knowledge of the authors, no research has however yet been conducted to understand the impact on sectoral profits of a delayed transition scenario, although initiatives looking at this issue are under way (notably led by UN Principles for Responsible Investment as part of their “Inevitable Policy Response” work).

ET RISK	UNEP FI “Extending our horizon”
Development of two transition scenarios tailored for financial risk analysis, mainly based on IEA’s scenarios, involving 30 parameters across 8 sectors	Development of sector level risk pathways for several sectors, including all of the above mentioned risk factors, based on PIK and IIASA’s scenarios
Road tested by Kepler Chevreux & the CO Firm for company-level climate risk modelling	Road tested by sixteen banks on their corporate credit portfolios

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

As explained above, no research has yet been conducted to understand the implications of delaying climate action for sectoral revenues. We therefore suggest to derive the key indicators needed to estimate sectoral profits under a delayed transition scenario from BaU & "smooth" transition scenarios, following a few principles detailed below.

General principles:

- For each sector, the **additional emissions occurring before 2025** under a delayed action scenario compared to a smooth transition scenario (date at which the transition starts) **have to be offset by 2040**, assuming a climate lag of 60 years (the temperature of 2100 is determined by the GHG emitted 60 years before).
- Additional emissions occurring before 2025 can be **offset through either a drop in production or a surge in energy efficiency**, depending on the sector considered. For example, cement being an essential material to build the infrastructures needed for the 10 billion humans expected by 2050, assuming a major drop in production wouldn't make sense (as confirmed by the IEA in ETP 2017), a surge in energy efficiency due to sudden R&D efforts seems more realistic.
- Fossil fuel prices under a delayed transition scenario evolve proportionally to demand; prices for other sectors slowly reach the levels of a "smooth" transition once the "late & sudden" transition starts.
- **No impact on gross or operating margins is assumed for building material industries** (Steel & Cement), as the authors didn't find any reasonable way to estimate this under a delayed transition scenario.
- In line with literature, **Carbon prices are assumed to be 1.5 times higher in 2040 under a "too late, too sudden" scenario** compared to a "smooth" transition scenario, to foster quicker energy efficiency improvements once the late & sudden transition has started *(See Advance_2020_Med2C ("smooth" transition scenario) and Advance_2030_Med2C (slightly delayed transition scenario) on IAMC's 1.5° online scenario database).*

Although the approach developed above represents a valuable first step in the development of a "too late, too sudden" transition scenario including all the indicators needed for financial analysis, there are several caveats to bear in mind. First, the approach overlooks possible interactions between sectors (in reality, emissions may decrease less than needed in an industry and more than needed in another) – although it takes into account risk propagation across industries (e.g. an increase in oil prices impacts airlines expenses). Second, in the absence of alternative solutions, it features a very simplistic price dynamic. Finally, in the absence of alternative solutions, it neglects changes in net margins for some sectors.

OUR TAKE ON THE ISSUE

Table 1.2 below details the sectors covered in our analysis, as well as the indicators used to estimate the change in profits under transition scenarios.

***Table 1.2** Sectors covered in the analysis and indicators used for profits calculation*

Sector	Target companies	Geography	Indicators used for profits calculation
Oil	Upstream oil	Europe, North America, South & Central America, Middle East, Africa, Asia Pacific, Eurasia	Production, Prices
Coal	Coal mining		
Natural gas	Upstream natural gas		
Power	Power generators (Coal, Gas, Solar, Wind)	Europe, USA, Latin America	Production, Prices, Levelized Cost of Electricity, Subsidies
Steel	Crude steel producers	Brazil, USA, Mexico, France, Germany, Italy	Production, Prices, Carbon prices, Carbon intensity
Cement	Cement producers		
Automotive	Car producers	World average	Production, Net margin by powertrain type
Aviation	Airlines (international)		Demand, Fuel efficiency, Fuel prices

TRANSITION RISKS IMPACT ON SHARE PRICES

HOW DO THE RISKS MANIFEST?

As explained above, climate change will impact companies' revenues and charges in many ways, with the amplitude of the effect varying depending on the sector they operate in. These changes in the companies' balance sheets will then impact their market value, as the demand for shares issued by weaken companies will decrease.

EXISTING LITERATURE ON THE ISSUE

To date, little research has been conducted to estimate the impact of transition risks on share prices, and none when it comes to a delayed action scenario. Among the existing literature, two main approaches can be identified:

Table 1.3 *Main approaches used by studies to estimate the impact of transition risks on share prices*

	TOP-DOWN approach	BOTTOM-UP approach
CORE PRINCIPLE	**Step 1:** Using an econometric model to simulate macroeconomic variables, among which are global share prices, under a transition scenario **Step 2:** Distribute the global change in equity value among economic sectors according to sector-specific weights	**Step 1:** Estimate, for each sector, the impact of the transition on revenues & costs, and assess the adaptative capacity of each industry **Step 2:** Use a valuation model to estimate the impact of these changes in revenues & costs on share prices
EXAMPLE	*CISL "Unhedgeable risks" (2015), DNB "An energy transition risk stress-test for the financial system of the Netherlands" (2018)*	*Ecofys/Navigant "Climate risks of 3 funds of Actiam" (2018), Carbon Delta VaR methodology, ET-Risks*

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

To estimate the impact of a "too late, too sudden" transition on share prices, supervisors could adopt either one of the two approaches, as long as the shocks resulting from a sudden decision are accurately represented. We however recommend the bottom-up approach as, for now, no macroeconomic model accurately modelling an abrupt transition exists.

OUR TAKE ON THE ISSUE

Based on our estimates of sectoral revenues, we ran a DCF (Discounted Cash-Flow) model to estimate the NPV (Net Present Value) of future cash-flows, starting in 2025. In line with Gordon's formulation of future dividends' flows (Gordon 1959), and assuming that dividends are proportionate to cash-flow, the difference in share prices between the "business as usual" and the transition scenario is assumed to equate the difference in NPVs. A world average of our regional results is displayed in Figure 1.5 below. See Annex 2 for more details on the methodology used.

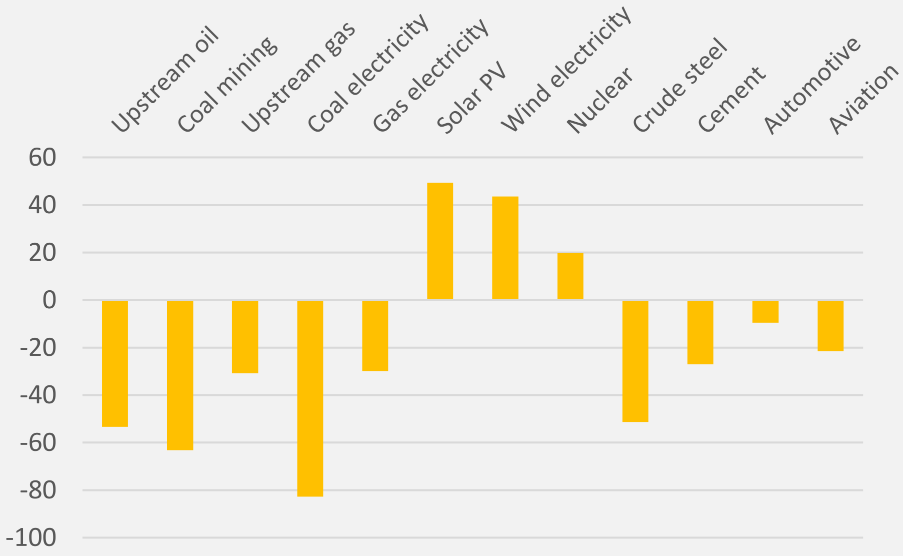


Figure 1.5 *Expected impact on share prices compared to baseline for a "too late, too sudden" transition scenario for key sectors, assuming a sudden repricing in 2025 (%) – World average*

HOW DO THE RISKS MANIFEST?

As explained above, climate change will impact companies' revenues and expenditures, as well as their assets and liabilities, with the amplitude of the effect varying depending on the sector they operate in. These changes in the companies' financial statements will then impact their probability of default, and therefore the value of their bond contracts.

Apart from its probability of default, prevailing interest rates are another major determinant of a bond's value (as they affect the discount rate of the bond's cash flows). As one cannot anticipate how a "late & sudden" transition would affect inflation, and thus long-term interest rates, we focus in this Section on default-risk as the sole driver of bond value changes under a transition scenario, and discount rates are kept constant across all scenarios.

EXISTING LITERATURE ON THE ISSUE

Table 1.4 below summarizes the existing studies assessing the exposure of corporate bonds to transition risks (See pg. 14 for a description of Top-Down & Bottom-Up approaches). To our knowledge, no research has yet been conducted to assess the impact of a "too late, too sudden" transition scenario.

Table 1.4 *Main studies estimating the exposure of corporate bonds to transition risks (in grey = resulting indicator)*

	TOP-DOWN approach	BOTTOM-UP approach
Quantitative result	• "Unhedgeable risk", CISL (2015) ➔ *% Changes in fixed income returns* • "An energy transition risk stress test for the financial system of the Netherlands", DNB (2018) ➔ *% Changes in credit spread & bond prices*	• "Operator Carbon Risk Tool" developed by Ecofys for the German government ➔ *Expected losses of German banks due to defaulted loans* • "Extending our Horizons", UNEP FI (2018) ➔ *Probabilities of default by sector*
Qualitative result	"Investing in a time of climate change", Mercer (2015) ➔ *Asset class sensitivity to transition risks*	"Heat map shows wide variations in credit impact across sectors", Moody's (2015) ➔ *Risk exposure score of 86 sectors to policy risks*

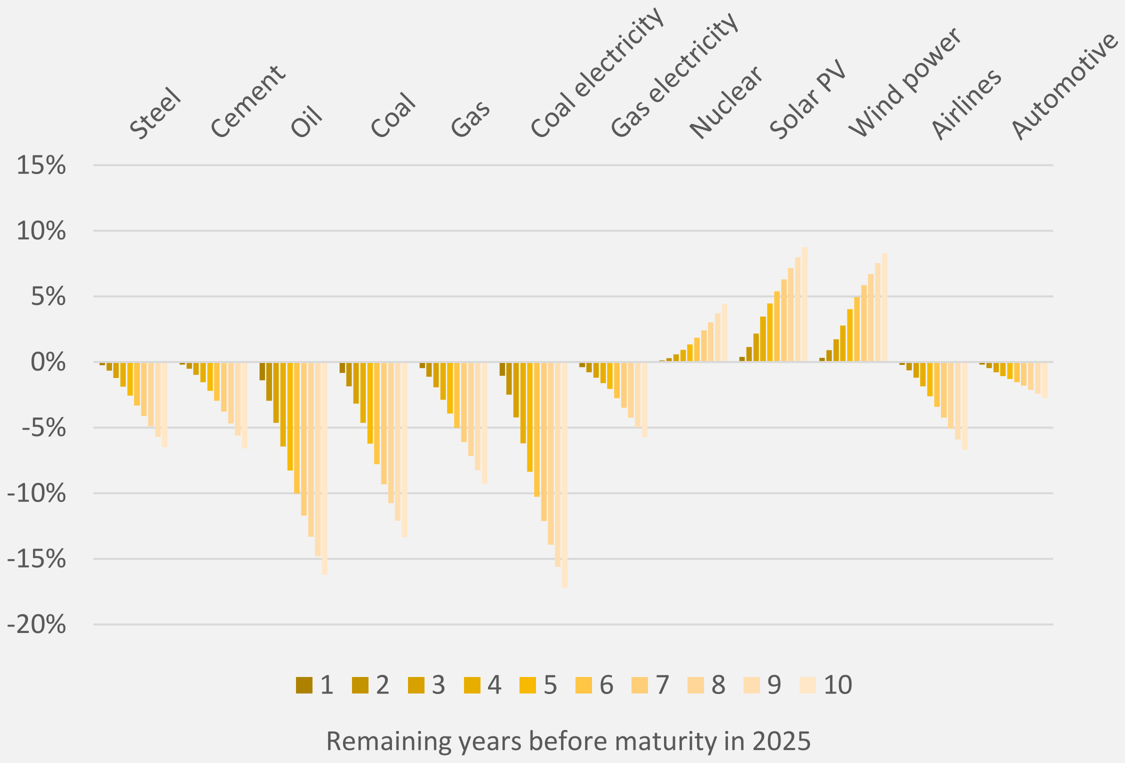
HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

Studies have shown that bonds' probabilities of default are heavily correlated with the main financial ratios of their issuers (Tang & Yan, 2010). Therefore, changes in sectoral revenues (see page 11) could be translated into **changes in key profitability ratios for each sector**, and a model, either expert judgment-based or statistical based, could then be used to estimate the impact on probabilities of default. These changes in the probabilities of default of the bonds could then be translated into changes in bond values. We used this approach in our example next page.

OUR TAKE ON THE ISSUE

We estimated the changes in bond values that could be expected in 2025 under a late & sudden transition scenario, depending on the remaining time to maturity of the bonds at that date, using the approach explained above: (1) deriving changes in probabilities of default from the changes in sectoral revenues estimated page 12 and (2) translating these changes in probabilities of default into changes in bond value. See Annex 2 for a detailed description of this approach. Figure 1.6 displays our results.

Figure 1.6 *Mean change in bond values in 2025 under a "too late, too sudden" transition scenario depending on their remaining time to maturity (%) – World average*



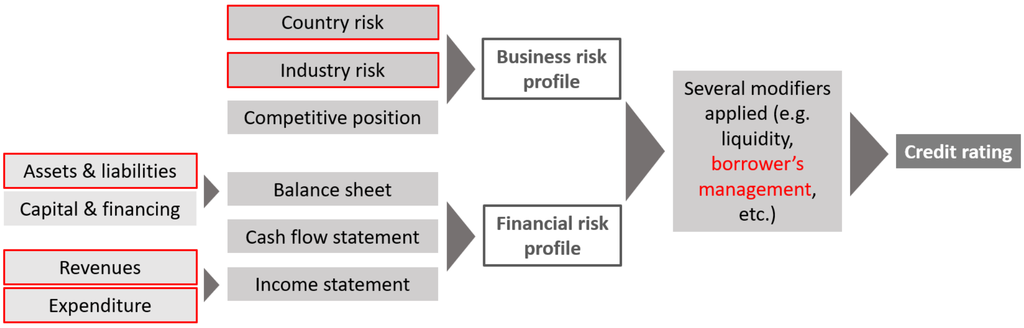
As illustrated by Figure 1.6, the bond value that is put at risk by a "late & sudden" transition increases as a function of the time to maturity of the bonds, driven by a rise in their 1-year probability of default as the transition progresses. As highlighted above for equity, Coal & Oil producers, as well as Coal power producers are the most strongly affected by a late & sudden transition.

It is worth noting that these results are sectoral averages, and thus do not consider the adaptative capacities of individual companies. This aggregated impact on bond value might hide significant disparities between companies of a given sector. As, in the context of regulatory stress-testing, changes in the value of entire asset classes are of more interest than changes in individual asset values, this isn't much of a concern. Our flexible bottom-up approach to estimating changes in sectoral profits, detailed page 12, could however be adapted to uncover these disparities. Global production trends taken from the IEA could be broken down to company level using a fair-share approach, while indicators related to energy efficiency and operating margin could be estimated on a case-by-case basis, based on the CAPEX and R&D expenditures already engaged by the company. Such an approach would enable the assessment of the consequences of the transition on companies with mixed revenue streams (e.g. revenues from carbon intensive and renewable power production at the same time).

HOW DO THE RISKS MANIFEST?

As explained above, climate change will impact companies' revenues and expenditures, as well as their assets and liabilities, with the amplitude of the effect varying depending on the sector they operate in. These changes in the companies' financial statements will then impact their probability of default, and therefore their credit rating. A few other factors in the model could be affected by transition risks, namely the country & industry risk levels, and the ability of the company's manager to deal with the risks. Figure 1.6 below provides a simplified overview of the factors integrated in credit rating models, with climate-impacted ones framed in red.

Figure 1.7 *Simplified credit rating model*



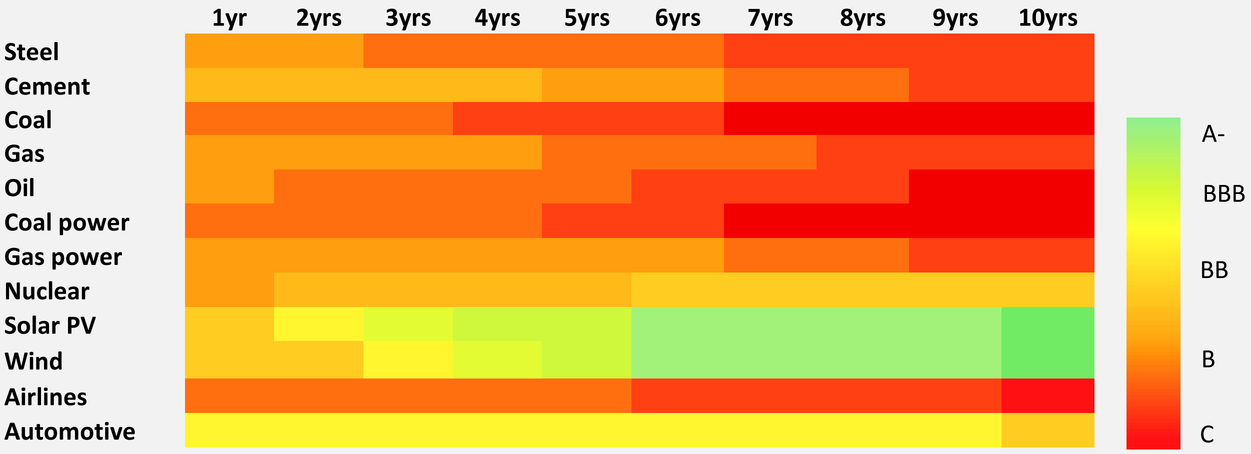
HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

Following the methodology descripted on page 14, supervisors could estimate how the changes in companies' profits driven by the transition would affect the probability of their bonds defaulting. Then, these changes in probabilities of default can be translated into changes in ratings, based on studies displaying the mean probability of default of each rating category (e.g. Moody's Annual Default Study).

OUR TAKE ON THE ISSUE

We applied the methodology described above to estimate the mean credit ratings of bonds tied to key sectors, depending on their remaining time to maturity in 2025 (date at which the transition starts).

Figure 1.8 *Mean credit ratings of the bonds tied to key sectors depending on their remaining time to maturity in 2025 – World average*



As expected, long-term bonds are more heavily affected by the transition than short-term ones, either positively or negatively depending on the sector.

IMPACT ON SOVEREIGN RATINGS

HOW DO THE RISKS MANIFEST?

The credit implications of a "too late, too sudden" low-carbon transition are captured in a broad set of factors that influence sovereign bonds' ratings. Figure 1.7 gives an overview of climate changes' main impacts on these factors.

Figure 1.7 *Key factors considered in sovereign rating models that will be affected by a delayed transition*

Institutional strength	Economic strength	Fiscal strength
A delayed transition would test the capacity of governments to build effective and predicable policies.	A delayed transition would impact economic activity, and therefore GDP (See page 10). High GDP concentration in exposed sectors increases the sovereign's susceptibility to transition risks.	A delayed transition would lead to increased expenditures (green investments, social policies, etc.), decreased revenues due to lower economic activity, and increased cost of borrowing.

EXISTING LITERATURE ON THE ISSUE

Both Moody's and Mercer assume transition risks to be unmaterial for both developed and emerging sovereign dept (Moody's, 2015; Mercer, 2015), mainly because they consider that "the transition would generally be managed in a way that maintains economic growth priorities" (Moody's, 2015). However, as discussed page 10, at the beginning of a "too late, too sudden" transition, growth could be significantly hit, and sovereigns' credit worthiness therefore altered.

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

The first step would be to quantify the impact of a "too late, too sudden" transition on countries' economic strength (GDP per capita could be taken as an estimate) and fiscal strengths (Dept-to-GDP could be taken as an estimate) at the desired time horizon (institutional strength being left aside for now, as no simple metric exists to quantify transition's impact on this factor). To date, only GDPpc forecasts under an abrupt transition scenario are available (See page 10).

Next step is to run a rating model to estimate the impact of these changes on sovereign ratings. Supervisors could either build a complete rating model based on a statistical analysis, or use historical sensitivity factors between changes in GDPpc and changes in credit ratings found in literature – if it exists for the country of interest. We used the latter approach below.

OUR TAKE ON THE ISSUE

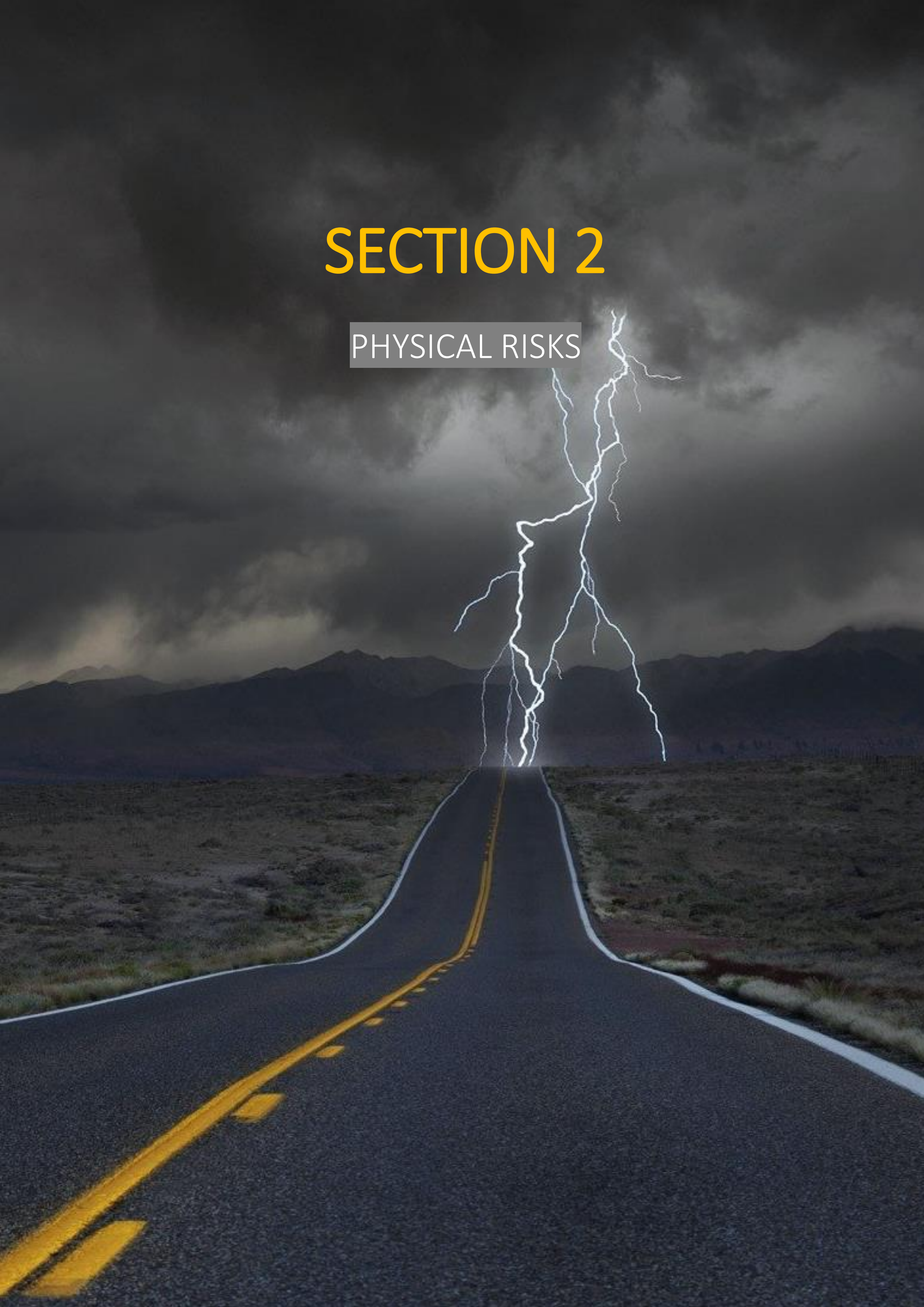
Using a sensitivity factor between GDP per capita and credit ratings found in literature (S&P, 2015), we estimated the rating impact of the GDP shock following an abrupt transition. As expected, only oil exporters' credit worthiness is affected, with emerging exporters being particularly exposed.

Table 1.6 *Changes in sovereign ratings due to an abrupt energy transition, 1 and 10 years after action has been taken*

	+ 1 year	+ 10 years
Advanced oil net importer	🟩	🟩
Emerging oil net importer	🟩	🟩
Advanced oil net exporter	🟩	🟨
Emerging oil net exporter	🟧	🟥

🟩	0-1 notch
🟨	1-2 notches
🟧	2-3 notches
🟥	+3 notches

It is important to keep in mind that OECD's delayed action scenario only considers the additional mitigation costs stemming from oil stranded assets, these results therefore do not represent the whole consequences of a delayed transition.



SECTION 2

PHYSICAL RISKS

WHAT ARE PHYSICAL RISKS AND HOW DO THEY MANIFEST?

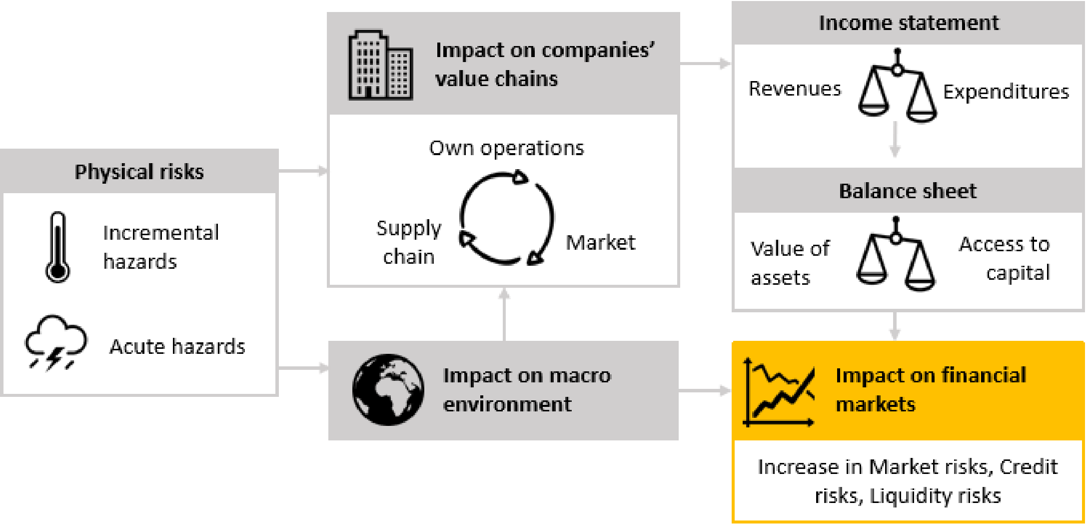
Climate change's consequences include both **incremental effects** (long-term change in the mean and variability of climate patterns) and **acute effects** (i.e. increase in extreme weather events' frequency and/or intensity stemming from the incremental changes).

Table 2.1 Example of acute & incremental consequences of climate change

Incremental changes	Acute weather events
Changes in mean temperature	Tropical storms
Changes in rain falls patterns	Floods
Long-term changes in water availability	Heat & Cold waves
Sea-level rise	Droughts
Coastal erosion	Wildfires
Air quality degradation	Extreme snowfalls

The term "**Physical risks**" refers to the risks arising from these incremental and acute changes on financial institutions' and/or businesses' value chains. They are characterized by their **geographical and sectoral specificity** (the exposure to different hazards varies a lot among economic sectors and world regions), and their **long-term horizon**. Figure 2.1 illustrates how such risks propagate thought the real economy up to the financial sector.

Figure 2.1 Propagation channel of physical risks to the real economy and the financial sector



Source: Authors, based on CICERO (2017)

HOW ARE PHYSICAL RISKS CONSIDERED BY FINANCIAL INSTITUTIONS?

Although financial institutions are increasingly aware of the risks stemming from climate change, little action has been taken to date to assess the potential impact of these risks on their assets (I4CE, 2018). Existing possibilities for institutions who want to conduct such an assessment include:

- The development of their own stress-testing tool, based on guidelines such as those provided in the "Navigating a New Climate" report (UNEP FI, 2018), but this solution is difficult and costly to implement
- The recourse to a private service provider (See I4CE, 2018), but the outcomes of such assessments are usually qualitative only, and the range of risk factors included in the assessment varies a lot among providers

HOW TO CHOOSE THE APPROPRIATE PHYSICAL RISKS SCENARIO? A TIME HORIZON ISSUE

Two approaches could be adopted to build a climate stress-test that assesses the impacts of climate physical risks, depending of the time horizon considered and the expected likeliness of the scenario:

- **Full damages scenario:** As explained before, climate change is a long-term risk. It will take some time to materialize, through incremental effects (temperature increase, sea level rise, etc.), leading to an increase in extreme weather events' severity and frequency. A stress-test could therefore be built based on a long-term scenario reflecting these slowly worsening physical manifestations of climate change, and their consequences on the financial sector.

\+ Even the consequences of climate change that will take time to materialize are included, and the preparedness of the financial sector to climate change as a whole can be assessed

\- Long term horizon not compatible with the traditional format of a stress test

- **Weather shock scenario**: To overcome this time horizon problem and produce a scenario that is more compatible with traditional stress-tests' format, a "shock" scenario could be built: Based on the idea that the occurrence and severity of extreme weather events will increase due to climate change, such a scenario could look at how a climate-related disaster impacts the financial sector.

\+ Short-term horizon compatible with the format of traditional stress tests

\- Only reflects the impact of selected weather events, not climate change as a whole, and ignores incremental risks, however they will likely be much more material on the long run than acute ones

OUR TAKE ON THE ISSUE

We detail below the main characteristics of both our long-term "full damages" and short-term "shock" scenarios.

Our "full damage" scenario	Our "weather shock" scenario
The long-term scenario that we use in this report is mainly based on OECD's 2015 report, "The economic consequences of climate change", assuming a **4.5° warming by 2100** (IPCC's RCP8.5). A wide range of incremental changes are included in the model, as well as consequences of hurricanes. We reviewed many other studies, some predicting much worse economic effect than the OECD on economic outputs (pages 22-23 discuss this issue), but only OECD's results were granular enough to be used in our analysis. Considering this, it is important to keep in mind that **our results likely are at the lower bound of the possible impact range**.	Our "weather shock" scenario assesses the economic impact of **once-in-250 years floods, hurricanes, wildfires and droughts** across all continents, mainly based on S&P's "The heat is on" report, as well as historical disaster data from the EM-DAT database. Due to the lack of data on the sectoral impact of acute weather events (See page 24), we didn't include a section discussing the implications of this scenario on sectoral value added.

HOW DO THE RISKS MANIFEST?

Both incremental and acute physical effects of climate change affect growth, through three main supply-side channels: by directly damaging and destroying output – for example crop losses during a drought, by damaging or destroying factors of production – for example factories, or by reducing (and sometimes boosting) factor productivity – for example drop in soil fertility. These effects are likely to vary greatly across countries, depending on (i) their physical exposure, as well as (ii) their socio-economic sensitivity to climate change and (iii) their capacity to adapt (UNEP, 2018). Demand-side effects could also complement these supply-side effects (e.g. increased demand for health services). See Annexed Figure 4.1.

EXISTING LITERATURE ON THE GROWTH IMPLICATIONS OF CLIMATE CHANGE

FULL DAMAGE SCENARIO

Most of the literature assessing the growth implications of climate change focus on incremental changes and their impact on long-term losses of outputs. These studies have broadly taken one of these three approaches (UNEP, 2018):

Table 2.2 *Main approaches used to estimate growth implication of climate physical risks*

	"Enumerative" approach	Modelling approach	"Historical role model" approach
DESCRIPTION	• Modelling of sectoral impacts of climate change (e.g. drop in crop productivity per ° of warming) • Multiplication of these elasticities by prices to quantify economic cost	Modification of the production function of macroeconomic models & addition of supply-side shocks	Use of variation in observed climatic conditions to statistically estimate the effect on GDP
PROS	Allows the inclusion of "non-market" impacts (e.g. human health, natural ecosystems, etc.)	Incorporates all the possible linkages between sectors	Empirical basis
CONS	• Limited empirical evidences • Assumes no compounding/interaction across sectors	Calibration of models has little empirical base	The effects of past climate fluctuations, generally on short timescales such as annual, may not be a good proxy for future changes

Table 2.3 provides the results of a CGE modelling approach (OECD's "Economic consequences of climate change" 2015 study) and of an historical role model approach (Burke et al., 2015), both assessing the GDP impact of a 4.5° warming by the end of the century.

Table 2.3 *GDP difference to baseline (%) under RCP 8.5 warming scenario after 5 and 40 years*

	Europe	America	Asia	Oceania	Africa	World
Long term effect of incremental changes (2060)						
Historical approach	15.0%	-19.0%	-27.5%	-15.0%	-40.0%	**-14%**
Modelling approach - CGE	-0.3%	-1.1%	-3.6%	-0.3%	-3.8%	**-2.4%**
Short term effect of incremental changes (5 years)						
Historical approach	1.8%	-2.3%	-3.4%	-1.8%	-4.9%	**-1.7%**
Modelling approach	-0.1%	-0.3%	-0.7%	0.0%	-0.7%	**-0.4%**

Table 2.3 shows that the estimated impact of climate change on GDP (assuming RCP 8.5 is followed) varies greatly depending on the approach adopted. Not only are the results different between a modelling and historical role model approach, significant differences also exist between different types of modelling approaches. Hence, GEMMES, a stock-flow consistent model endogenously representing private debt and its impact on the economy, estimated a 1.2% drop in global growth rate by 2060 (considering a Stern damage function), compared to the 0.1% drop in 2060 growth rate modelled by the OECD (Giraud et al., 2017).

Due to the lack of sectoral and/or geographic granularity of most of the studies mentioned before, we only considered OCED's results in the analysis that follow. It is therefore important to keep in mind that our results likely are at the lower bound of the possible impact range.

SHOCK SCENARIO

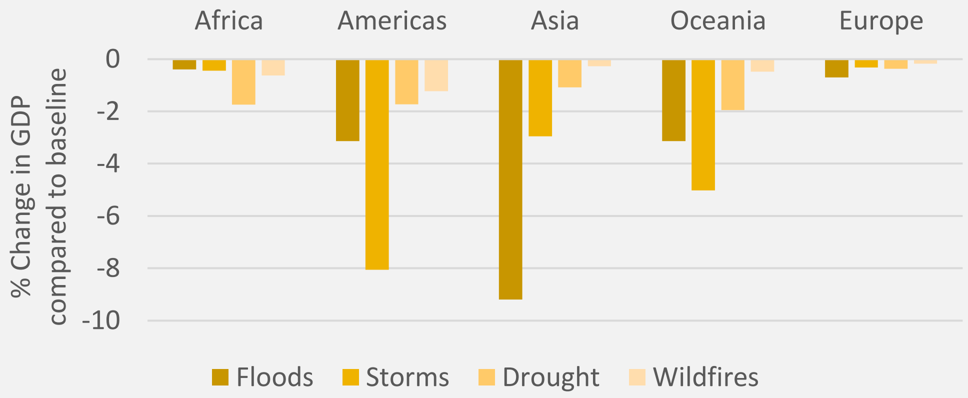
Since the 90's, significant attention has been given to the assessment of the economic consequences of natural disasters. Studies have shown that the impact of disasters on growth depends on many factors: although the long-term effects of medium-intensity events might be positive (due to the stimulus provided by reconstruction needs to numerous sectors), both short and long-term impacts of major events are overall negative, with their magnitude depending on the type of event and the economic sector considered (Loayza et al., 2009). Literature however highlights the numerous drawbacks and biases of available data and techniques used to estimate economic impacts, threatening the reliability of existing losses estimates (CERE, 2017).

While climate change is expected to increase the severity of extreme weather events and therefore worsen their economic impacts, very few studies have been conducted on this issue. According to the existing literature, not enough data is available for disasters other than tropical storms and floods to build meaningful losses estimates (Ranson et al., 2016; S&P, 2015). S&P's "Heat is on" report is, to our knowledge, the only study quantifying the impact of climate change on the drop in GDP per capita following major weather events (once-in-250 tropical storms and floods). To do so, they built on a specialized database that gathers the damages, in monetary values, due to major weather events across the world (Swiss RE Sigma Explorer database), and a forward-looking climate model (Climada).

OUR TAKE ON THE ISSUE

Figure 2.2 that we propose hereafter builds on S&P's results regarding floods and hurricanes (see paragraph above), that are complemented with estimates of GDP drops following droughts and wildfires. To obtain these estimates, we converted economic damages caused by past droughts and wildfires, as displayed in the EM-DAT database, into a GDP shock based on a ratio between damages and GDP shock computed with S&P's data. Results for droughts and wildfires are therefore backward looking only, whereas results for floods & hurricanes, taken from S&P, consider the future impact of climate change.

Figure 2.2 *GDP shock (% losses compared to baseline) following a once-in-250-years disaster*



These results are only preliminary estimates, and could be improved by **running a statistical model on historical data to assess the correlation between GDP and severe droughts/wildfires occurrence** in regions of interest, instead of relying on a ratio between economic damages and GDP as we did.

HOW DO THE RISKS MANIFEST?

Physical climate effects, both acute and incremental, impact the profits of companies in sensitive sectors through two main channels: On the supply side, companies suffer a drop in productivity from destruction of assets and physical impediment of operations, and have to bear an increase in supply chain costs. On the demand side, consumption decreases as a result of increase prices of the companies' goods and/or of complementary goods. Companies aren't exposed the same to these risks depending on the sector they operate in, their geographical situation, their preparedness, and their adaptative capacity. The most exposed sectors include agriculture, power, transport, building, fossil fuels, materials, and services – which suffers from indirect effects stemming from the other sectors. The following sections provide some guidance to estimate climate change's impact on sectoral outputs.

EXISTING LITERATURE ON THE SECTORAL EFFECTS OF CLIMATE CHANGE

When it comes to assessing climate change's effects on sectoral outputs, incremental effects are much more widely studied than acute weather events.

INCREMENTAL EFFECTS

Studies estimating the economic impacts of incremental climate change's effects have broadly taken one of these two approaches:

Table 2.4 *Main approaches used by studies to estimate the sectoral effects of climate physical risks*

	"Enumerative" approach	Modelling approach
Description	Modelling of impacts of climate change on sectoral production. e.g. agriculture specific impact model, power specific impact model, etc.	Modification of the production & damage functions of traditional IAM/CGE models to compute the effects on sectoral value-added
Pros	• Allow a high level of sectoral and geographical granularity • Can account for non-market impacts	• Incorporates all the possible linkages between sectors • The outputs are economic indicators (usually value added) englobing all the shocks mentioned above
Cons	• Limited empirical evidences • Assumes no compounding/interaction across sectors • The outputs are biophysical indicators, not economic ones ➔ the translation into economic values implies high level assumptions	• Calibration of models has little empirical base • Non-market impacts are not accounted for
Example of studies using the approach	"Navigating a New Climate", UNEP FI (2018)	"Investing in a time of climate change", Mercer (2015)

Both approaches could be used by supervisors to build a stress-test, although we recommend the latter, as the translation of production data into economic values in the "enumerative" approach implies high-level assumptions, neglecting market dynamics, that are likely to significantly bias the results.

ACUTE WEATHER EVENTS

When considering acute weather events, two types of data have to be gathered: the future frequency of extreme events, as well as the impact of these events on sectoral value added. Figure 2.5 presents the state of research on both these issues.

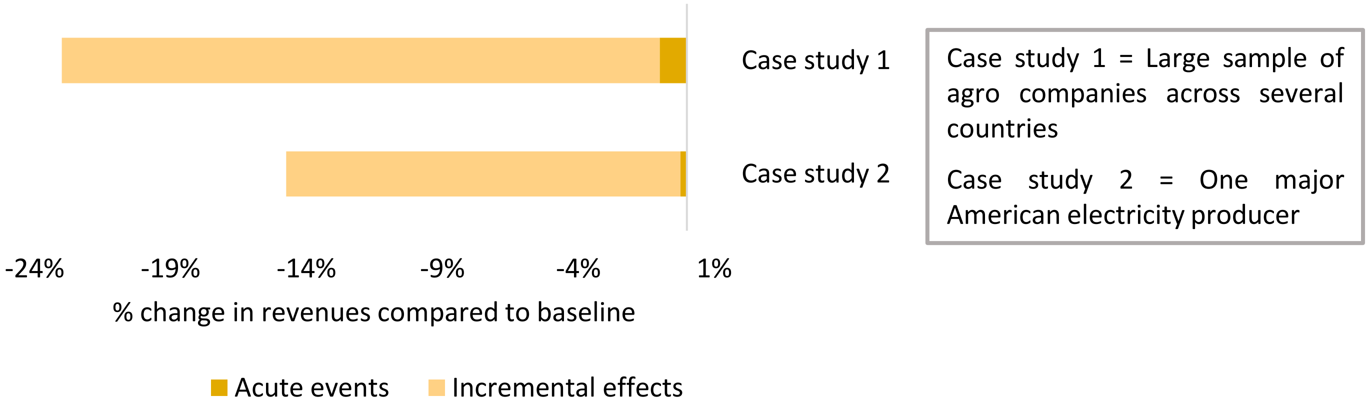
Table 2.5 *Information needed to include acute weather events into a stress-testing framework*

	Extreme weather events frequency	Impact on sectoral value added
State of research	Several heatmaps exist that display the current & forecasted risk level of a given region regarding a given weather event (e.g. Aqueduct Water Risk Atlas WRI for drought).	The only available figures are: Historical drop in revenues in the agricultural sector due to major weather events; Historical drop in power plant's productivity due to water shortages/heat waves; and damages to infrastructures due to extreme events. To date, **the eclectic and fragmentary nature of this data prevents it from being used to estimate a solid relationship between a weather event and the associated drop in sectoral revenues.**
Way forward	Cross these risk maps with the location of all physical assets in climate-sensitive sectors (power plants, oil extraction facilities, etc.), and land use maps, to estimate the proportion of assets exposed to a given level of risks.	A statistical analysis could be conducted to analyze the financial statements of companies in key sectors affected by major events in the past

EXPECTED MAGNITUDE OF IMPACTS

Figure 2.3 hereafter presents some of the results disclosed in the "Navigating a new climate" report (UNEP FI, 2018). Although the results aren't representative of the whole economy, as derived from two individual bank's portfolios, they suggest **that the impacts of acute weather events are likely to be of much smaller magnitude than those driven by incremental changes**.

Figure 2.3 *Impact on companies' revenues of acute events & incremental changes driven by climate change, 4° scenario*



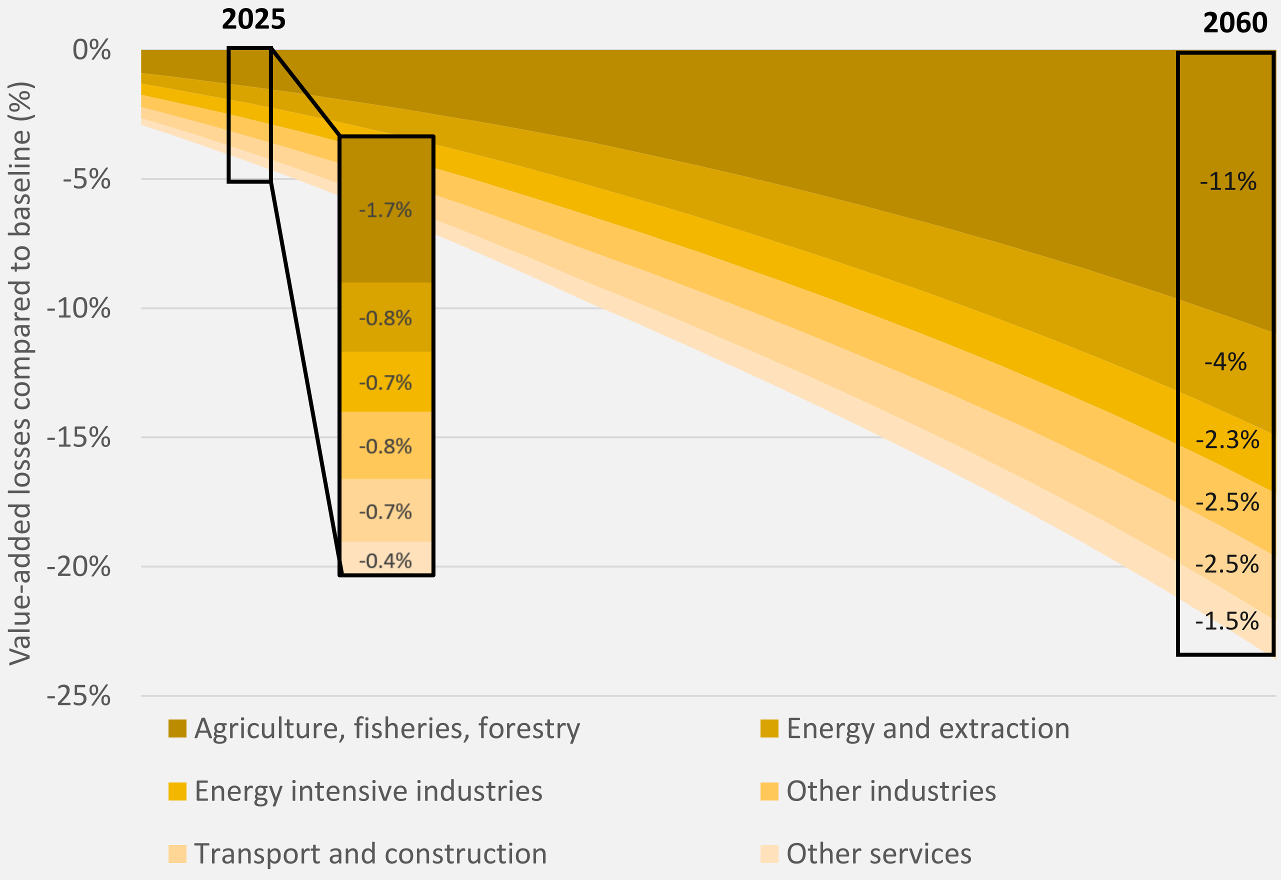
Source: Authors, based on UNEP FI, 2018

OUR TAKE ON THE ISSUE

In our analysis of the impacts of climate change on sectoral outputs, we focused on incremental effects for two main reasons: First, as mentioned before, the available data on the economic effects of acute weather events is too fragmentary to be used. Second, the few figures that we found suggest that the consequences of extreme weather events would be rather low compared to incremental effects (See p.24). We decided to opt for the "modelling" approach, as the outputs of such models are economic indicators (losses in value-added), contrary to the "enumerative" approach, where important assumptions have to be made to turn physical production values into economic revenues.

Figure 2.4 shows the result of our analysis based on a study by OECD (2015) which assesses the impact of a 2.5° warming in 2060 (equivalent to a 4.5° warming by the end of the century) on global and regional sectoral revenues – See page 21 for more details on the study.

***Figure 2.4** Global sectoral value-added losses due to incremental climate change effects – 2.5° warming by 2060 (% change to baseline)*



Source: Authors, based on OECD data (2015)

The agricultural sector is the most exposed to physical risks, with 11% of its total value added being threatened by climate change in 2060. Then come energy and extraction, transport & construction, industries, and services.

It has to be noted that within each sector, there will inevitability be leaders and laggards. Identifying the differences between these is critically important when trying to assess the vulnerability of a given institution, and thus a more in-depth approach would have to be adopted to do so.

HOW DO THE RISKS MANIFEST?

As explained above (See page 24), climate change will impact companies' revenues and expenses in many ways, with the amplitude of the effect depending on the sector they operate in. These changes propagate to the companies' balance sheets and thus impact their market value, as the demand for shares issued by weaken companies will decrease.

EXISTING LITERATURE ON THE IMPACT OF CLIMATE CHANGE ON SHARE PRICES

While a few studies have been conducted to estimate the credit risks stemming from climate change, little has been done regarding share prices. The most comprehensive study on this matter is the 2015 report by Mercer, titled "Investing in time of climate change". In this report, they estimated the sensitivity of several asset classes – including equity, to both incremental ("Resource" risk factor) and acute ("Impact" risk factor) climate change effects. The methodology they used to estimate these sensitivity factors is however not disclosed, and the expectable changes is share prices per sector isn't explicitly quantified. Schroder's also conducted an analysis on this matter ("The forgotten physical risks", 2018), but the methodology adopted is too simplistic to be used as a source of inspiration to build a proper stress-test. Finally, a few commercial consultancies assess the impact of these risks at company level, but they mostly neglect to estimate the quantitative impact on share prices (I4CE, 2018).

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

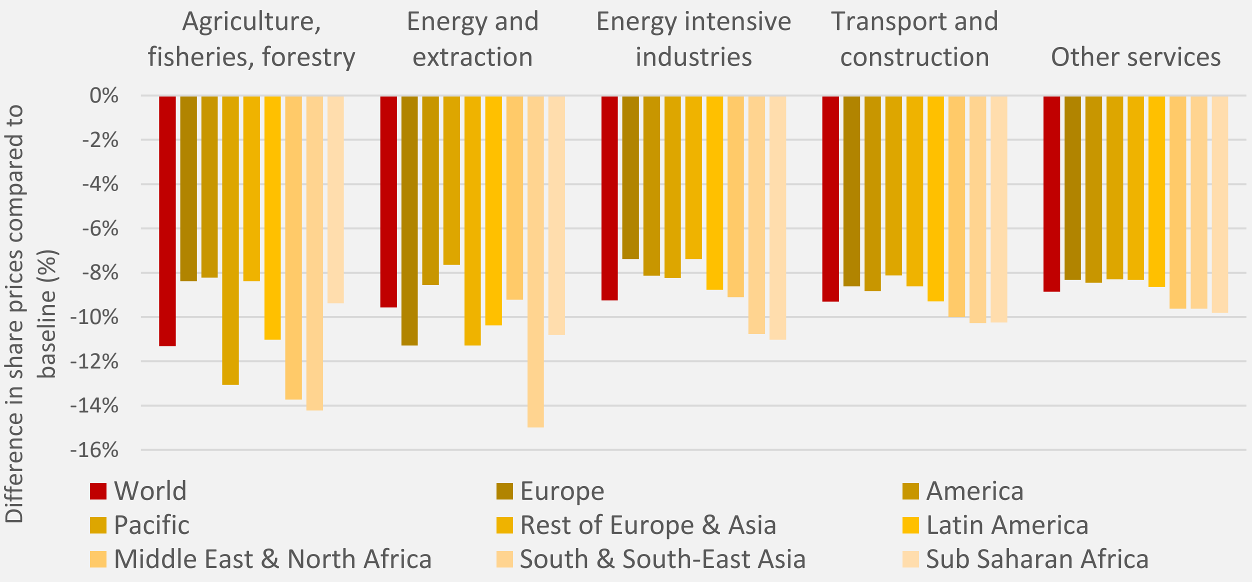
"FULL DAMAGE" SCENARIO

In line with what has been done by Kepler Chevreux and the CO-FIRM regarding transition risks (See Section 1), we recommend running a DCF model, based on estimations of sectoral revenues under a climate change scenario, to estimate the NPV of future cashflows. The difference in share prices between the "no damage" and the climate change scenarios is assumed to equate to the difference in NPVs. Figure 2.5 below displays our results obtained using this approach.

OUR TAKE ON THE ISSUE

We applied the DCF approach to our sectoral value added estimates from page 25.

Figure 2.5 *Difference in share prices between a "4.5° warming by 2100" & "no damage" scenarios for key sectors and world regions (%)*



Source: Authors, based on OECD data (2015)

The agricultural sector is the most exposed to physical risks, with almost 12% of its value being threatened by incremental climate effects. Then come the energy sector, transport and construction, industries, and services. As expected, emerging markets are more exposed than developed markets.

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

SHOCK SCENARIO

At current, little research has been conducted to understand how extreme weather events impact sectoral revenues. For this reason, running the DCF model used for the “full damage” scenario wasn’t possible.

Two solutions therefore exist:

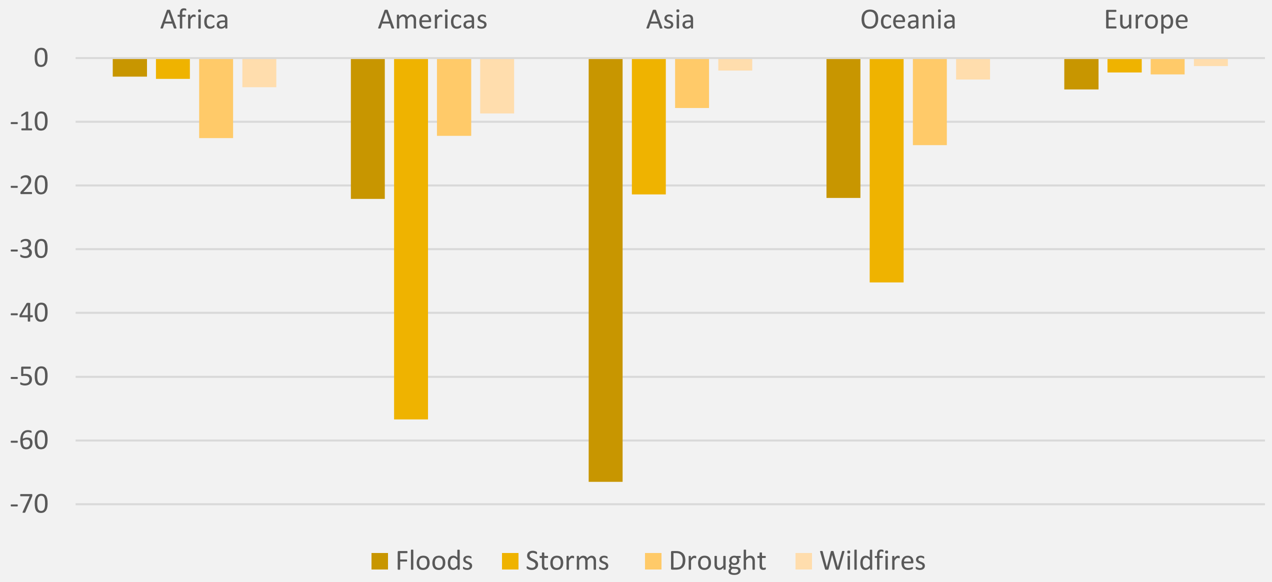
- **Approach 1: Derive the shock on share prices from the GDP estimates**. Although literature shows that there is little correlation between GDP and share prices on the short-term, such a relationship can be found in traditional regulatory stress-tests. Using a sensitivity factor between GDP growth and share prices found in traditional stress-tests, share prices could then be derived.
- **Approach 2: Run a statistical analysis.** A statistical model could be built based on historical data to estimate the mean impact of past disasters on share prices for key sectors in the region of interest, i.e. estimate a sensitivity factor between the severity of the weather event and the impact on share prices

Although the latter approach would likely provide the most reliable results, it is more complex to execute in practice.

OUR TAKE ON THE ISSUE

Using the first approach explained above (based on the correlation between GDP and share prices found in ESRB stress tests), we estimated the impact of a once-in-200 years flood, storm, drought and wildfire on share prices. As they are based on correlations between GDP and share prices that may not exist in practice, these results are however to be considered as being preliminary estimates which should be consolidated using Approach 2 mentioned above.

Figure 2.6 *Impact of once in 250 years disasters on share prices - 1 year after (%)*



It has to be noted that damages for droughts are very likely underestimated, as the GDP estimates which are the basis of this analysis do not consider the full consequences of these events (they only consider short term damages and do not encompass long-term impacts on the economy, which are significant in the case of droughts).

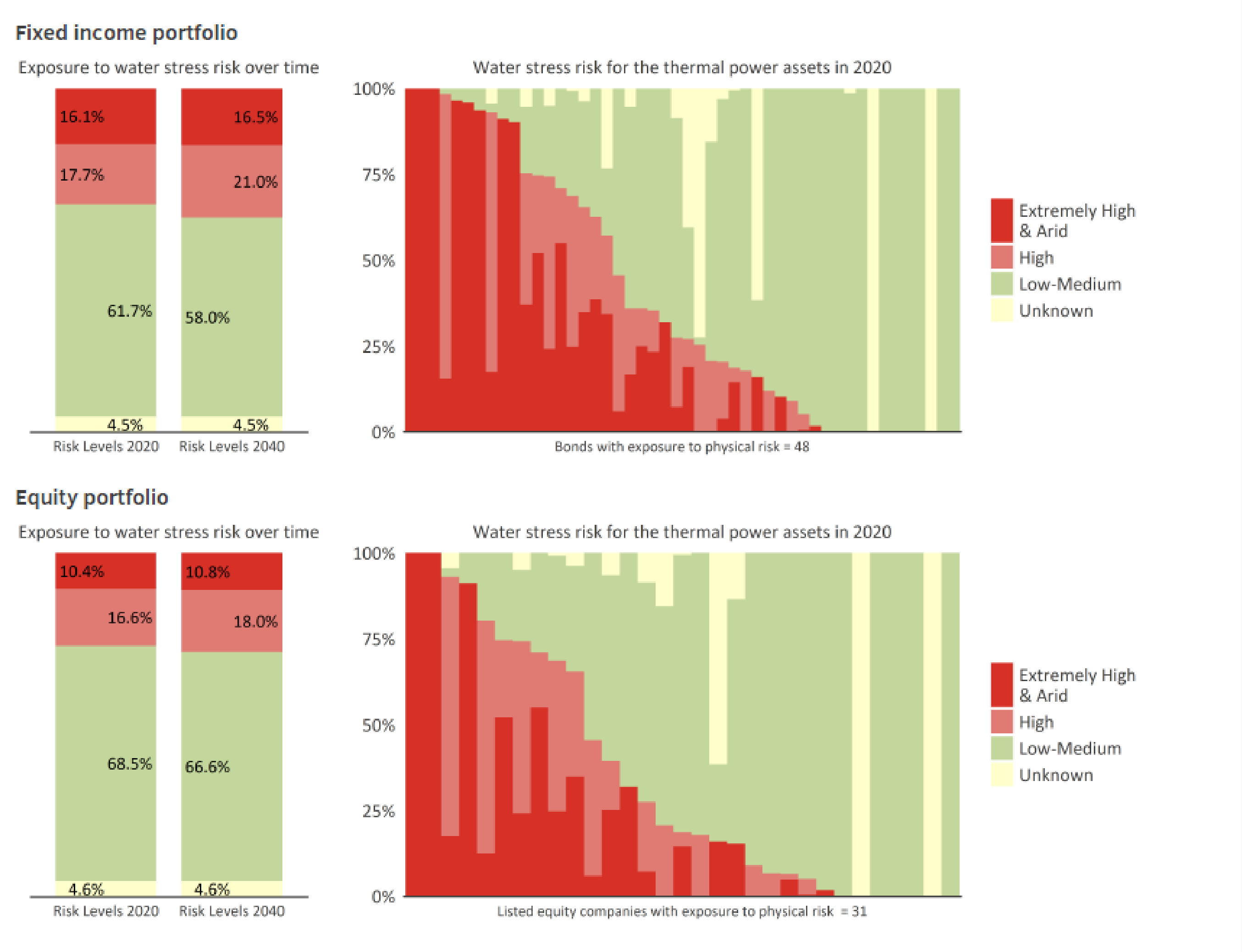
ASSET ANALYSIS BY THE CALIFORNIA INSURANCE COMMISSIONER

In 2018, the California Insurance Commissioner's Office conducted a climate scenario analysis project on insurance companies operating in California. The project, developed in partnership with the 2° Investing Initiative, focused on transition risk. At the same time, it provided a first attempt by a financial supervisor to look at both physical and transition risks in an integrated approach.

Although the physical risk analysis only focused on 'transition-related sectors' – notably fossil fuels and the power sector – it provided visibility on an asset by asset level for these sectors as to their exposure to physical risks. Predictably, the results showed significant divergence within a sector for a range of different risks. The figure below highlights the findings for bonds and equity exposures' of companies owning thermal power plants. The findings demonstrate the extent to which companies may have 100% of their thermal power plant assets exposed to extreme water stress risks and as low as 0%. Thus, while the sectoral approaches and macro approaches highlighted in the previous pages may be useful for a more high-level stress-test, they will hide differences in outcome on an asset by asset basis – differences that may be significant.

Moving forward, financial supervisors may want to explore approaches that integrate sectoral analysis with – for specific sectors and data permitting – more granular asset by asset reviews, of the kind currently being developed by a range of commercial and non-profit organizations.

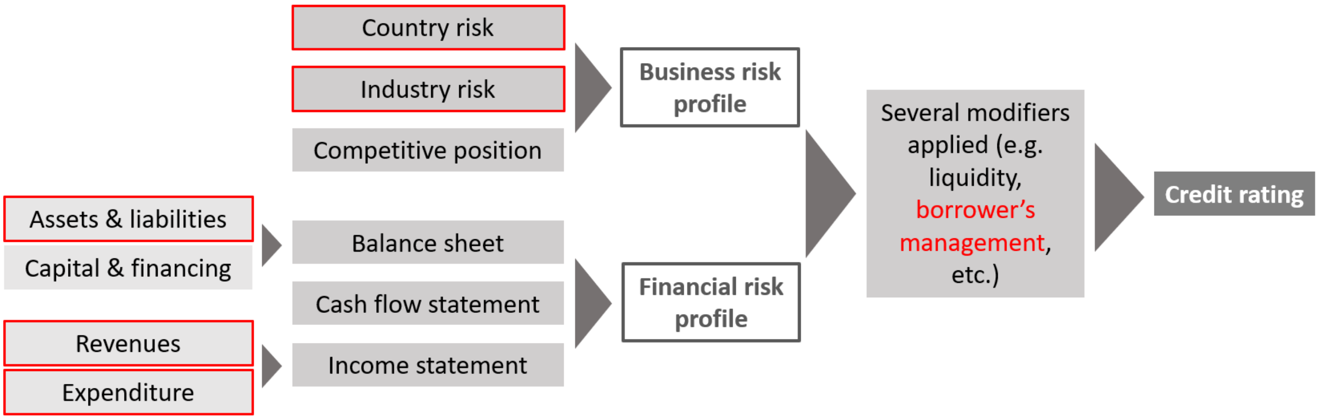
Figure 2.7 *Water risk level for thermal power assets. (In the charts on the right, each bar represents a single bond and stock, respectively)*



HOW DO THE RISKS MANIFEST?

As explained above, climate change will impact companies' revenues and expenditures, as well as their assets and liabilities, with the amplitude of the effect varying depending on the sector they operate in. These changes in the companies' financial statements will then impact their probability of default, and therefore their credit rating. A few other factors in the model could be affected by physical risks, namely the country & industry risk levels, and the companies individual risk management strategy and overall adaptive capacity. Figure 2.8 below provides a simplified overview of the factors integrated in credit rating models, with climate-impacted ones framed in red.

Figure 2.8 *Simplified credit rating model*



EXISTING LITERATURE ON THE IMPACT OF CLIMATE CHANGE ON CORPORATE CREDIT RATINGS

WHAT IS THE IMPACT OF CLIMATE EVENTS ON CREDIT RATINGS TO DATE?

Credit rating agencies are starting to quantify climate-related risks' impact on corporate credit ratings. S&P launched a first report in 2015, titled "How environmental and climate risks factor into global corporate ratings", aiming at quantifying the percentage of their rating actions driven by environmental and climate factors. They released an update of the report in 2017. According to this analysis, E&C factors were the key drivers for 1.2% of their rating actions since 2015, with physical climate risks making up **0.5%** of this figure, the main sectors affected being power, gas, oil and metals to a lesser extent (S&P, 2017). While this figure may appear negligible, it still significantly increased since S&P's former report two years before, suggesting that the increase in physical risks that will be driven by climate change might result in a significant impact on credit ratings.

WHAT COULD BE THE IMPACT OF CLIMATE CHANGE ON CREDIT RATINGS?

Few studies have been conducted to estimate the impact of future climate change's effects on corporate credit ratings. The most comprehensive and exhaustive attempt to develop a methodology on this matter has been conducted by the UNEP FI in their "Navigating a New Climate" report released in 2018. The results displayed in the study suggest a rather limited impact of physical risks on credit ratings (between no effect to 1 notch). The only other in-depth analysis conducted on the subject is, to our knowledge, the UNEP's drought stress-test which assess the impact on drought events on corporate probability of default in the US, China, Brazil and Mexico. The methodology that we propose hereafter builds on these two reports.

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

Studies have shown that both macroeconomic factors and firm-level ratios impact credit ratings, with the latter explaining a larger part of ratings at firm-level (Tang & Yan, 2010). However, at sectoral level, which is the focus of this exercise, global economic trends are likely to play a major role. Two possibilities therefore exist to do estimate probabilities of default:

- Approach 1: Derive the changes in probabilities of default from firm-level ratios: the changes in sectoral revenues could be translated into **changes in key profitability ratios for each sector**, and a **statistical model** could then be built to estimate the impact on probabilities of default.
- Approach 2: Derive the changes in probabilities of default from macroeconomic variables: A **sensitivity factor between GDP growth rate and probabilities of default** (estimated by running a statistical model on historical data), could be used to estimate the economy-wide change in probability of default attributable to climate change, and this change could then be distributed among sectors according to their contribution to the drop in GDP. We used this approach in our example below.

Finally, these changes in probabilities of default can be translated into changes in credit ratings, based on the historical relation between credit ratings and probabilities of default. Approach 1, although it would likely provide the most reliable results, is more time and data-intensive, we therefore used Approach 2 in our examples below.

OUR TAKE ON THE ISSUE

"FULL DAMAGE" SCENARIO

Using a sensitivity factor between GDP and probability of default found in literature (Tang & Yan, 2010), we estimated the change in credit rating resulting from incremental climate effects by 2060. Table 2.6 hereafter presents our results. Using the same approach, we also estimated changes in 5y CDS credit spread (Table 2.7).

Table 2.6 *Change in credit ratings due to climate change's incremental effects in 2060, by sector and country*

	Agriculture, fisheries, forestry	Energy and extraction	Energy intensive industries	Transport and construction	Other services
World	🟥	🟧	🟩	🟧	🟩
Europe	🟩	🟩	🟩	🟩	🟩
America	🟩	🟩	🟩	🟧	🟩
Pacific	🟧	🟩	🟩	🟩	🟩
Rest of Europe & Asia	🟧	🟩	🟩	🟩	🟩
Latin America	🟧	🟩	🟩	🟩	🟩
Middle East & NA	🟥	🟩	🟩	🟧	🟧
South Asia	🟥	🟥	🟧	🟥	🟧
Sub Saharan Africa	🟥	🟩	🟧	🟧	🟩

🟩	0-1 notch
🟧	1-2 notches
🟥	+2 notches

Table 2.7 *Change in 5y credit spread due to climate change's incremental effects in 2060, by sector and country*

World	🟧	⬜	🟩	⬜	⬜
Europe	🟩	🟩	🟩	🟩	🟩
America	🟩	🟩	🟩	⬜	⬜
Pacific	🟨	🟩	🟩	🟩	🟩
Rest of Europe & Asia	🟧	🟨	🟩	🟩	🟩
Latin America	🟨	⬜	🟩	🟩	🟩
Middle East & NA	🟧	🟩	🟩	🟨	🟨
South Asia	🟥	🟥	🟨	🟨	🟨
Sub Saharan Africa	🟨	🟧	🟧	🟨	🟨

🟩	0-30 basis point
⬜	30-50 basis point
🟨	50-100 basis point
🟧	100-200 basis point
🟥	>200 basis point

As expected, our results show a limited impact of climate change on credit ratings 40 years from now in developed countries, while emerging and least developed countries are more strongly affected. Of course, the time horizons considered go way beyond those in stress-tests.

OUR TAKE ON THE ISSUE

SHOCK SCENARIO

Based on a study assessing the impact of a growth rate shock on corporates' probability of default (Simons & Rowles, 2008), and using the growth estimate computed above (See page 23), we estimated the impact of once-in-200 years floods, storms, droughts and wildfires on credit ratings. Table 2.8 displays our results.

Table 2.8 *Change in mean credit ratings for the whole economy following a major weather event*

	Floods	Storms	Drought	Wildfires
Africa	🟩	🟩	🟧	🟨
America	🟥	🟥	🟧	🟩
Asia	🟥	🟥	🟩	🟩
Oceania	🟥	🟥	🟧	🟩
Europe	🟩	🟩	🟩	🟩

🟩 0-1 notch
🟨 1-2 notches
🟧 2-3 notches
🟥 +3 notches

As expected, Asia (driven by South-East Asia), America (driven by the Caribbean), and Oceania are the most exposed regions. Tropical storms and floods are the disasters causing the worst rating impact.

HOW DO THE RISKS MANIFEST?

The credit implications of physical risks are captured in a broad set of factors that influence sovereign bonds' ratings. Figure 2.9 gives an overview of climate changes' main impacts on these factors.

Figure 2.9 *Key factors considered in sovereign rating models that are affected by climate change*

Institutional strength	Economic strength	Fiscal strength
Extreme weather events test the capacity of governments to deal with infrastructure damages, displaced population, etc. while incremental changes such as sea-level rise challenge the state's planning capacity.	Both acute and incremental effects of climate change impact economic activity, and therefore GDP. High GDP concentration in exposed sectors increases the sovereign's susceptibility to climate risks.	Climate change will lead to increased expenditures (social programs, reconstruction & mitigation costs, costs of displacement), decreased revenues due to lower economic activity, and increased cost of borrowing

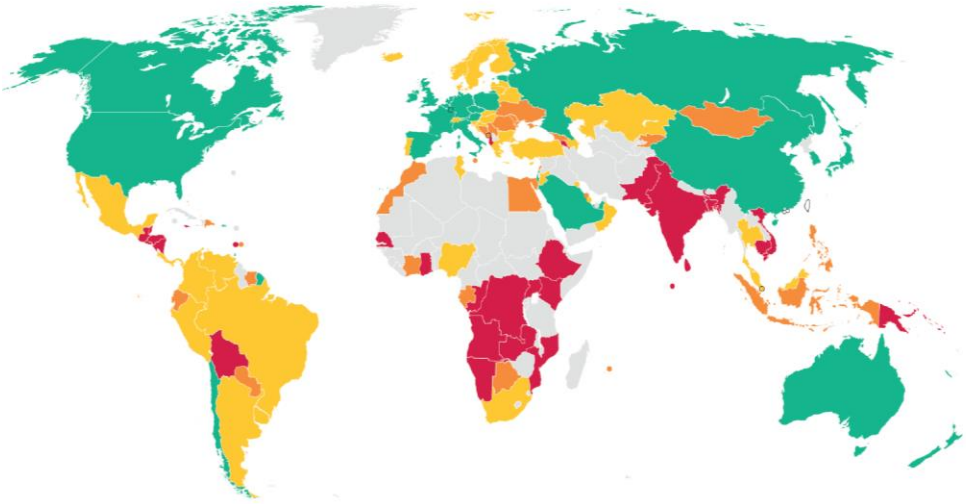
Source: Authors, based on Moody's (2016) and S&P (2017)

According to S&P (2015), the economic and fiscal factors are likely to play the most significant role in the rating impact of climate change.

EXISTING LITERATURE ON THE ISSUE

To date, no downgrade by a major credit rating agency has been attributed to climate risks. However, both Moody's and S&P become increasingly vigilant about climate impacts and their possible fiscal and economic consequences (UN Climate Change, 2018). Hence, in 2016, Moody's assessed the exposure of its rated sovereigns to selected climate change's impact - (See Figure 2.10). **South Asian and African countries were identified as being the most at-risk regions**.

Figure 2.10 *Susceptibility of Moody's rated sovereign to climate change's acute effects*



Most susceptible Susceptible Less susceptible Least susceptible

As for S&P, it published in 2015 the "Heat is on" report, estimating the rating impact of climate-driven floods & hurricanes by 2050. Caribbean and Asian ratings were identified as being the most exposed to these two risks.

To our knowledge, no further research has been conducted to estimate the impact of acute weather events on sovereign ratings, and **none has been conducted regarding incremental changes**.

HOW COULD THE RISKS BE CONSIDERED BY FINANCIAL SUPERVISORS?

The first step would be to quantify the impact of both incremental changes and acute weather events on countries' economic strength (GDP per capita could be taken as an estimate) and fiscal strengths (Dept-to-GDP could be taken as an estimate) at the desired time horizon (institutional strength being left aside for now, as no simple metric exists to quantify climate's impact on this factor). To date, only GDPpc forecasts under climate change scenarios are available.

Next step is to run a rating model to estimate the impact of these changes on sovereign ratings. Supervisors could either build a complete rating model based on a statistical analysis, or use historical sensitivity factors between changes in GDPpc and changes in credit ratings found in literature – if it exists for the country of interest. We used the latter approach below.

OUR TAKE ON THE ISSUE

Using a sensitivity factor between GDP per capita and credit ratings found in literature (S&P, 2015), we estimated the rating changes under both our scenarios.

Table 2.9 *Changes in sovereign ratings under our "full damages" and "shock" scenarios*

"FULL DAMAGE" SCENARIO

	Long-term effects (2060)
Africa	🟩
America	🟩
Asia	🟨
Oceania	🟩
Europe	🟩

SHOCK SCENARIO

	Floods	Storms	Drought	Wildfires
Africa	🟩	🟩	🟩	🟩
America	🟩	🟨	🟩	🟩
Asia	🟧	🟩	🟩	🟩
Oceania	🟩	🟨	🟩	🟩
Europe	🟩	🟩	🟩	🟩

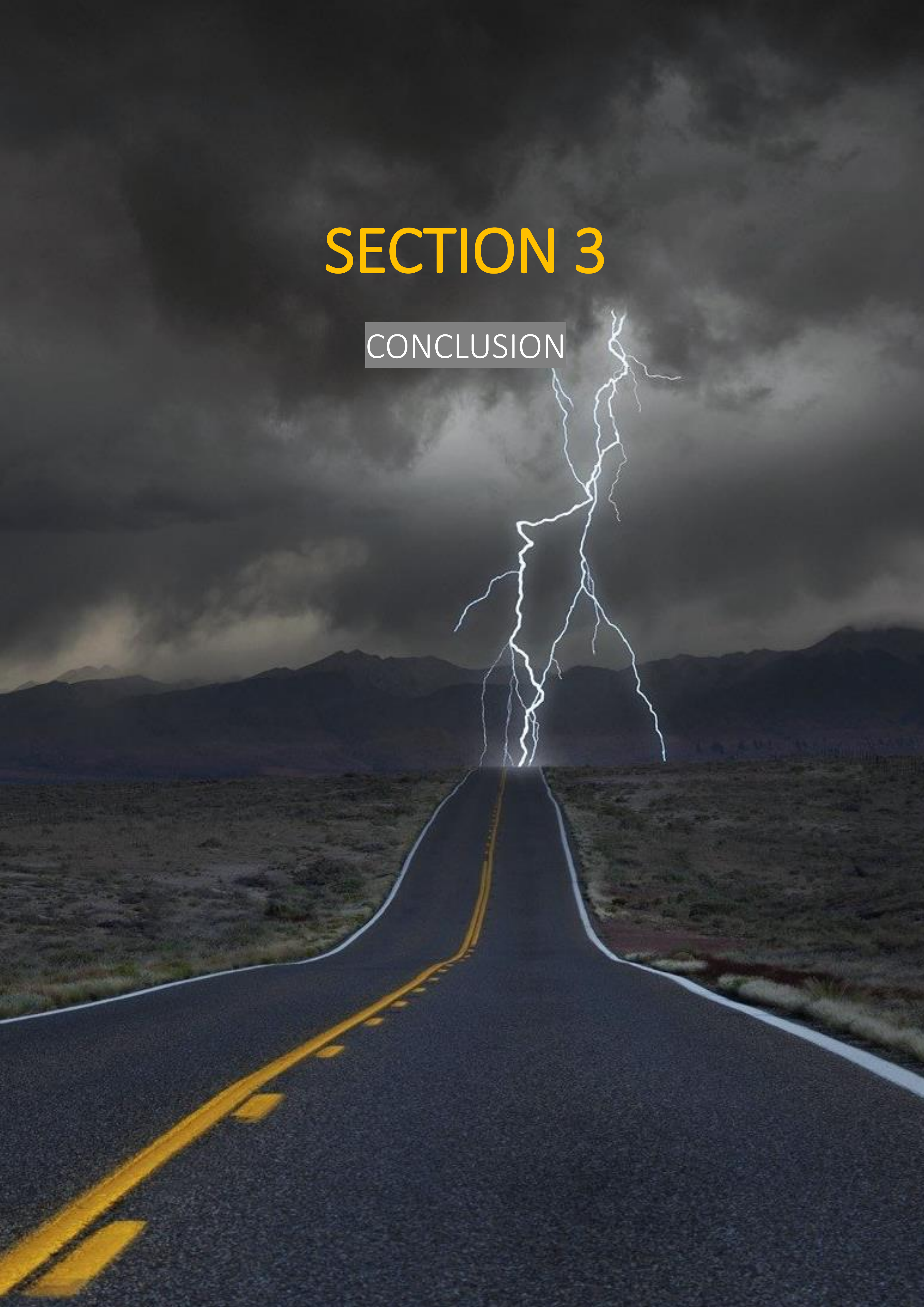
🟩 0-1 notch 🟨 1-2 notches 🟧 2-3 notches

According to these results, Asian sovereigns are the most exposed to both extreme weather events and long-term climate change's effects, followed by American and Pacific sovereigns.

The figures displayed are likely to be at the **lower bound of the impact range**, as only GDP-reflected changes are taken into account, whereas other factors playing a role in ratings will be impacted by climate change. The impact of droughts, particularly in Africa, may also be underestimated, as the economic damages displayed in the EM-DAT database and used for these calculations don't factor all the long-term consequences of droughts on the economy. Specific countries, such as Netherlands for floods, will also be affected more than the regional average.

SECTION 3

CONCLUSION



CONCLUSION

A WAY FORWARD ON CLIMATE STRESS-TESTS AND SCENARIO ANALYSIS

This report provided guidelines to build an adverse climate scenario that can be used directly in traditional stress-tests, as well as alternative climate stress tests of the kind pioneered by a number of financial supervisors around the world. The analysis can be used as inspiration and input by financial supervisors in designing their own stress-tests. 2° Investing Initiative is currently partnering with a number of financial supervisors on turning this 'stress-test' into a direct application for regulated entities.

Crucially, it is worth noting that a meaningful stress-test or scenario analysis approach requires bottom-up data on companies. At least for transition risks, the data needs go beyond traditional sector classification data of the kind already collected by financial supervisors and regulated entities. Further data needs can be addressed through asset-by asset data and / or corporate reporting. The combination of top-down stress-tests and asset level data for example has been applied by the Bank of England and is currently being applied with the European Insurance and Occupational Pensions Authority.

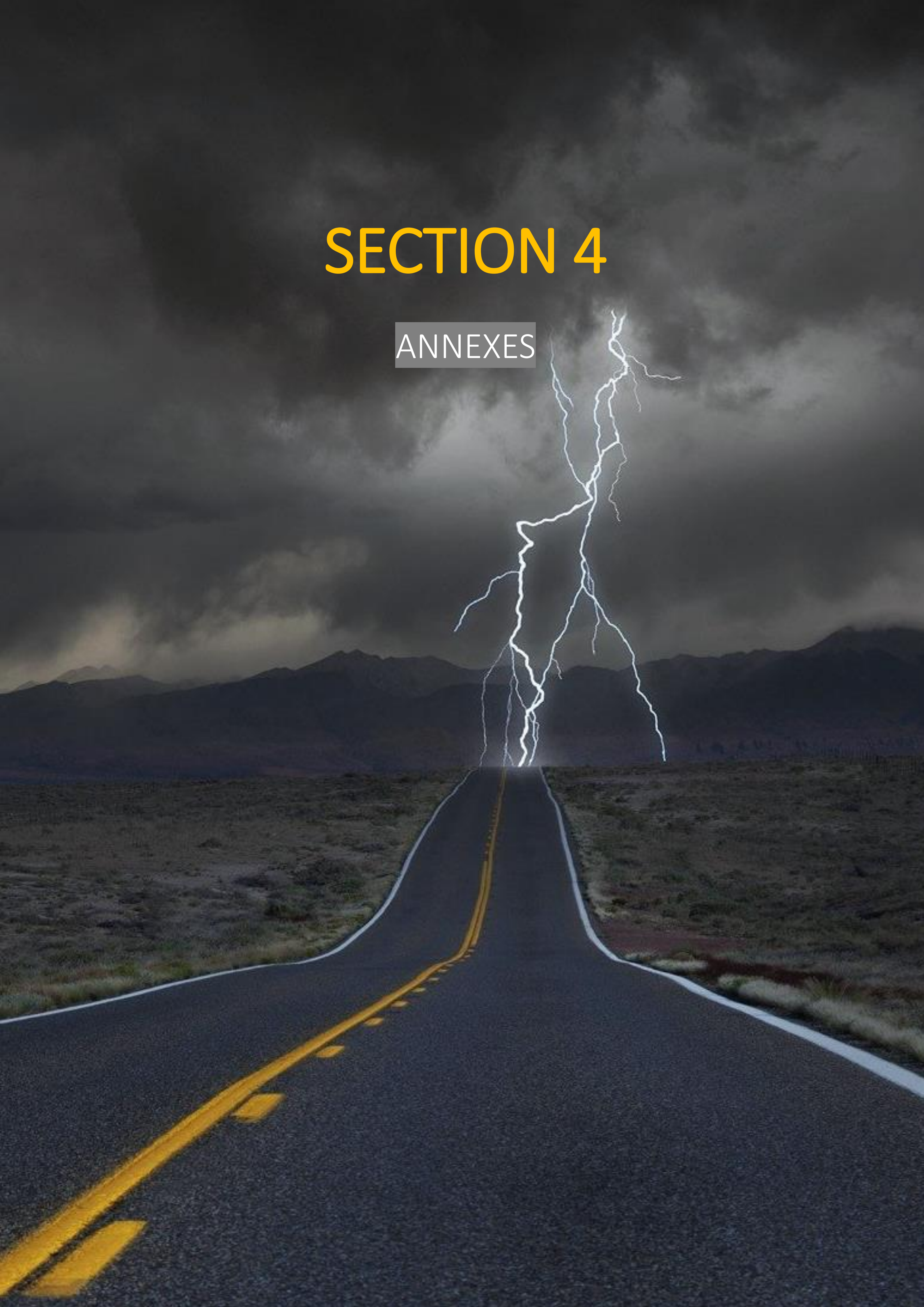
The results and findings here are exemplary and demonstrate what financial supervisors 'can' do. They do not profess to be the 'right answer' on these risks, which are both uncertain in terms of scale and the nature by which they will materialize. Many roads lead to Rome on this topic. In some ways, the advantage of exploring stress-testing frameworks of the kind discussed in this report is exactly the fact that the 'right answer' is not necessarily needed. For financial supervisors, understanding 'worst case' potential outcomes is different to actually having to define what the outcome will ultimately be. In other words, the scenarios developed in this report have been designed to simulate potential worst case outcomes without bias as to the probability of them materializing in one way or another. The authors thus invite readers to form their own opinions, disagree with these results, and suggest alternatives. This report doesn't have to be wrong for others to be right, in the world of stress-testing risks in financial markets.

TOWARDS LONG-TERM FINANCIAL SUPERVISION

One key challenge in designing this report, and for stress-test approaches on climate and other long-term risks moving forward, is the lack of infrastructure around long-term supervision. Many of the risks explored in this report are material over long-term time horizons, but at times appear muted over the time horizon traditionally used in stress-tests (<3 years). As a result, some of the findings in this report suggests that climate risks are not material for a stress-test, even if they may lead to significant and material economic and social dislocation. Moreover, at times, physical risks may appear less material than transition risks in financial markets simply as a function of the concentration of transition risks and the more short-term nature over which they are likely to materialize. This of course is not consistent with the scientific reality that physical risks will be significantly more harmful for GDP and global welfare than transition risks, across most if not close to all modelling work done in this field.

By extension, even where climate scenarios exist and are developed – as they are in this report – to help financial supervisors monitor these risks, they meet a financial supervision infrastructure that is not necessarily designed to integrate these issues. This is true both immediately in terms of the stress-testing frameworks, but also more generally in terms of how results of stress-tests are then translated into supervisory actions and regulatory guidelines. More work is needed here, not just to translate climate risks into stress-testing scenarios, but also to translate these scenarios into supervisory instruments that can drive action. Of course, it is critical to note that sometimes this action may actually run counter to societal objectives. One example in the context of physical risks is the extent to which they increase financing costs for the most vulnerable countries and regions, directly negatively affecting the ability to finance adaptation and thus both mitigate risks and ensure broader distributed economic prosperity. Adaptation after all remains a key commitment of the Paris Agreement in Art. 2.1b. While it is no doubt in the public interest to surface these issues, it may not be in the public interest that associated findings create more economic disparity and punish the vulnerable – potentially ultimately aggravating macro risks.

While outside of the scope of this report, these questions remain crucial and are a key component to integrating climate and long-term risks into financial supervision and into capital allocation decisions by financial institutions.

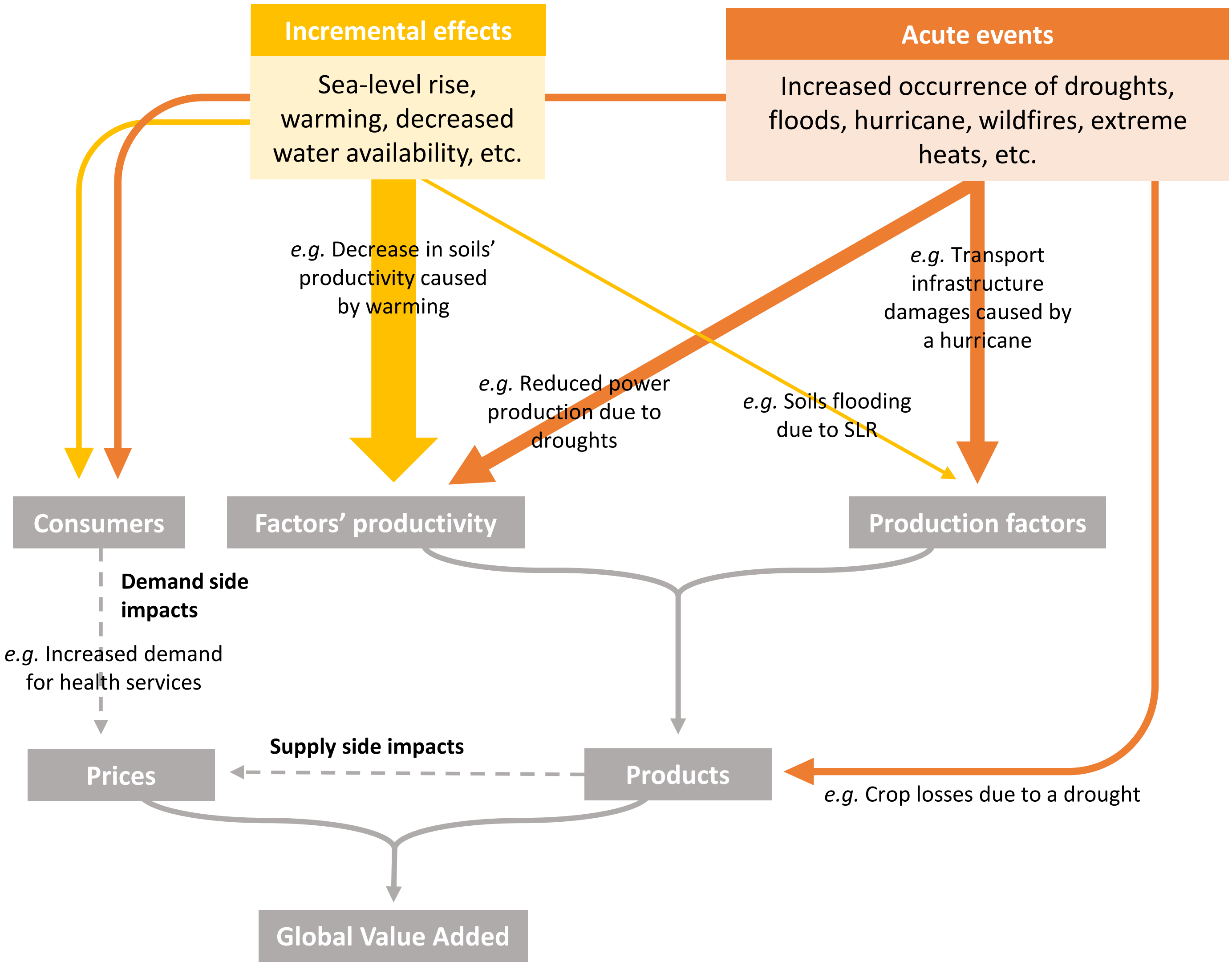


SECTION 4

ANNEXES

ANNEXE 1

Annex 1 *Overview of climate change's impact on global economic outputs*



ANNEXE 2

- **Estimating equity value under a “too late, too sudden” transition scenario**

To estimate changes in share prices under a “too late, too sudden” scenario, we rely on Gordon’s formulation of future dividends’ flows (Gordon 1959). The equity market price V_E at time t_0 is given by:

$V_{E,t_0=\frac{D_1}{r-g}}$ with D_1 being the expected dividends for the next year, r being the cost risk of capital for the company, and g being the dividend’s growth rate.

Assuming that dividends for a given year are proportional to the net profits of the company for this year, and explicitly modeling the future evolution of profits, we derive the following formula:

$$\boldsymbol{V}_{\boldsymbol{E},\boldsymbol{t_0}=\boldsymbol{\alpha}\sum_{\boldsymbol{t}=\boldsymbol{t_0}}^{\boldsymbol{t}*}\frac{\boldsymbol{P_t}}{(\boldsymbol{1}+\boldsymbol{r})^{\boldsymbol{t}}}*(\boldsymbol{1}+\boldsymbol{x})}$$

With Pt being the profits made by the company in year t (modelled as explained in Section 2.1), t* the date until which we explicitly model cash-flows, x the percentage of modelled value in the terminal value, and α the proportionality coefficient between net profits and dividends.

In simple words, the value of equity for a given company is assumed to equate the Net Present Value of its future cash-flows.

We set $r = 5\%$; $t_0 = 2025$ (i.e. we assume a sudden repricing of equity in 2025, date at which the TLTS transition starts, due to a market sentiment shock), $t^* = 2040, x = 10\%$ and α = 1 for all scenarios.

The difference between $V_{E,t0}$ under the Business as Usual and the “too late, too sudden” scenarios is the equity value put at risk by the transition.

- **Estimating corporate bonds’ value under a “too late, too sudden” transition scenario**

The most influential factors that affect a bond's value are prevailing interest rates (as they affect the discount rate of the bond’s cash flows) and the bond's probability of default. As one cannot anticipate how a “late & sudden” transition would affect inflation, and thus long-term interest rates, we focus in this Section on default-risk as the sole driver of bond value changes under a transition scenario, and discount rates are kept constant across all scenarios.

Step 1. Estimating the probability of default under a transition scenario

Studies have shown that bonds’ probabilities of default are heavily correlated with the main financial ratios of their issuers (Tang & Yan, 2010). Among the financial ratios contributing most to the prediction of default, NI/TA (net income over total assets) is likely to be the most strongly affected by companies’ profit losses due to the transition.
We assume that a X% change in net income translates into a X% change in NI/TA ratio (i.e. we assume that total assets are not affected by the transition) and, based on Zmijewski’s bankruptcy model (Zmijewski, 1984), we then derive the marginal effect that a change in NI/TA would have on the probability of the bond defaulting over the course of the upcoming year. Zmijewski’s probit model is as follows:

$$PD = \varphi(-4.336 - 4.513\frac{NI}{TA} + 5.679\frac{TL}{TA} + 0.004\frac{CA}{CL}) \qquad (1)$$

ANNEXE 2

Where PD is the 1-year probability of default, ϕ the standard normal cumulative distribution function, NI/TA net income over total assets, TL/TA total liabilities over total assets, and CA/CL current assets over current liabilities.

In a probit model, the marginal effect of a change in one of the explanatory variables on probability of default is given by:

$$\frac{\partial Y}{\partial x_i} = \beta_i \phi(\beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n)$$

Which, in our case, translates into the following formula:

$$\Delta PD_t = \Delta \frac{NI}{TA_t} * -4.513 * \phi(-4.336 - 4.513 \frac{NI}{TA_{BaU,t}} + 5.679 \frac{TL}{TA_{BaU,t}} + 0.004 \frac{CA}{CL_{BaU,t}}) \quad (2)$$

With:
φ being the standard normal probability density function;
ΔPD_t being the additional probability that the bond default in year t+1 under a transition scenario compared to a BaU scenario;
$\Delta \frac{NI}{TA_t}$ being the difference in NI/TA in year t between a BaU scenario and a transition scenario;
and $\frac{NI}{TA_{BaU,t}}, \frac{TL}{TA_{BaU,t}}, \frac{CA}{CL_{BaU,t}}$ being the "baseline" financial ratios under a BaU scenario in year t.

This gives us the **additional probability that a bond defaults within one year under a transition scenario compared to a Business-as-Usual scenario**.

Step 2. Estimating the value of a bond under a transition scenario

Let X represent the present value of a bond's cash flow stream. The standard way to value a bond with a given probability of default in year t (PD_t) is to take each possible value of X, multiply it by its probability and sum the results:

$$V_j = \sum_{t=1}^{T} X_t PD_t (\prod_{k=0}^{t-1} (1 - PD_k)) \quad (3)$$

With Vj being the value of bond j, T being the maturity date of the bond, and PD_t being the probability of default computed in Section 2.4.1.

To come up with an expression for the X_t, the following variables need to be defined:

Fj is the face value of the bond j, Cj is the coupon rate of the bond j, R is the recovery rate in case of default, rj is the discount rate for the cash flows.

For a bond expected to mature in T time periods, with coupons paid every period, the present value of its cash flow stream, assuming no default, can be written as:

$$X_T = \sum_{t=1}^{T} \frac{C_j F_j}{(1 + r_j)^t} + \frac{F_j}{(1 + r_j)^T} \quad (4)$$

By combining both equations (3) and (4), we get:

$$V_j = \sum_{t=1}^{T} \frac{C_j F_j}{(1 + r)^t} (\prod_{k=1}^{t} (1 - PD_k)) + R_j F_j \sum_{t=1}^{T} \frac{PD_t}{(1 + r)^t} (\prod_{k=0}^{t-1} (1 - PD_k)) + \frac{F_j}{(1 + r)^T} \prod_{k=1}^{T} (1 - PD_k)$$

In the example displayed page 15, we set R_j = 38%*, F_j = 1000$, C_j = 50%, r = 5%.

**Historical recovery rate of senior bonds (Moody's, 2017)*

SECTION 5

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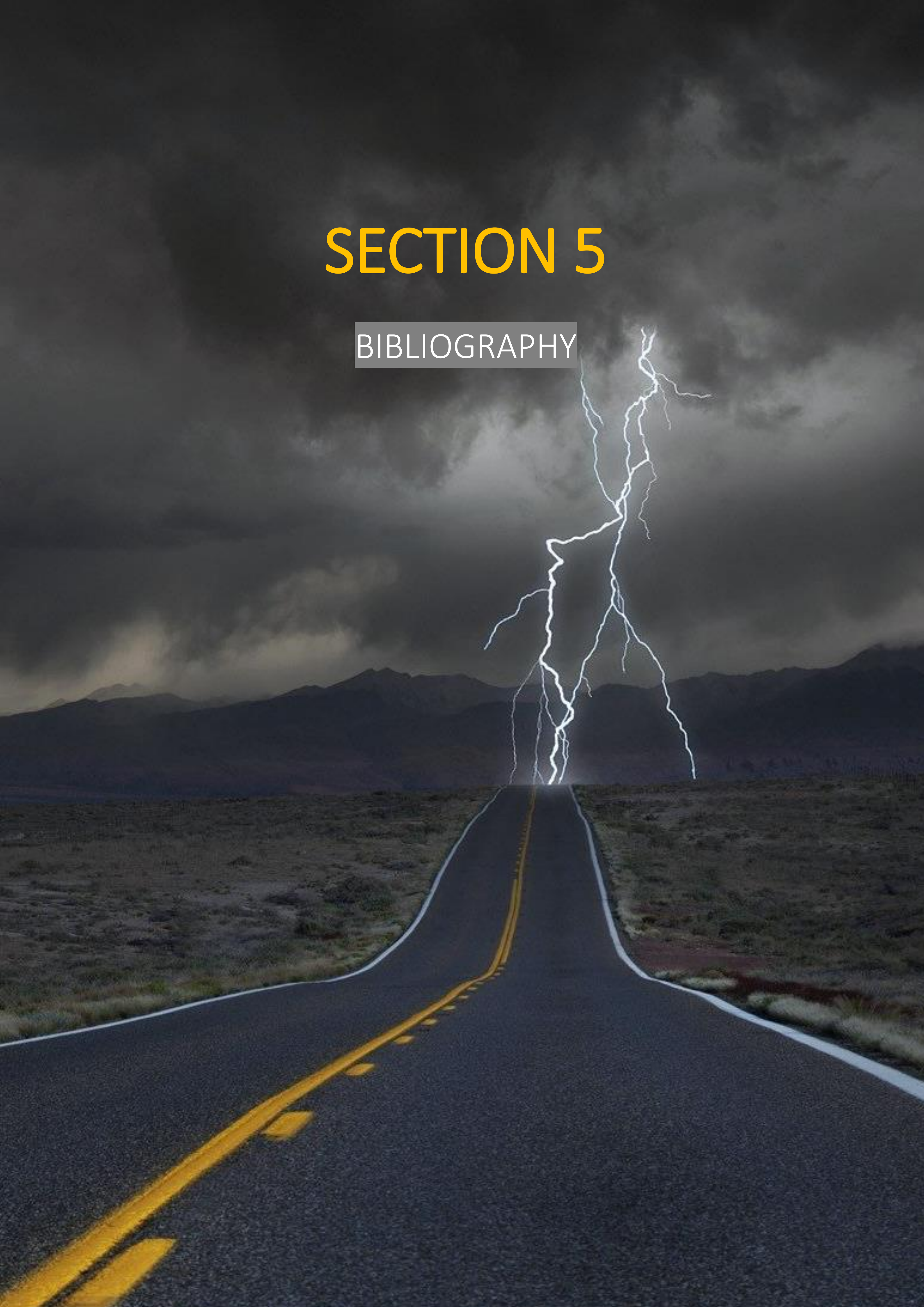

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