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# A guide to building climate-financial scenarios for financial institutions

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## Headlines

- The financial system needs to develop understanding of the channels through which significant greenhouse gas emission reductions – the climate transition – will affect economic activity and influence financial risk and returns on investments.
- The ultimate aim of climate financial scenarios has to be to enable assessment of risk and reward at the level of the economic agents that financial firms have exposure to. This is a different goal to that of policy-oriented scenarios of greenhouse gas emission reductions which aim to identify the mix of actions aligned with temperature and emission targets.
- Climate transition scenario analysis should be incorporated into both risk management and strategic planning activities. For risk management purposes, scenarios should help deepen understanding of climate related drivers of market, credit, operational and other risks. For strategic planning, firms need to identify the changes to their business models necessary to support the transition to a lower carbon economy.
- One size does not fit all, and scenarios need to address the scope, size and exposures of individual firms.
- A single scenario will not answer all questions. To capture the full extent of uncertainty associated with climate transition, financial firms need to develop multiple scenarios that present different, plausible visions of climate risks and opportunities.
- To help users understand the financial implications of climate change, scenarios should contain well-developed narratives. Transition scenarios are complex and require rich narratives to explain policy and technological assumptions, develop missing elements, and provide the right information about economic agents' behaviours.
- Transition scenarios need to provide an interface between policy and technological assumptions and financial risk models. The financial industry will need to develop additional scenario related modelling capabilities as Integrated Assessment Models (IAMs) are unable to provide all the information financial firms require.
- Climate financial scenario analysis is challenging. The climate transition will create structural economic change that is not straightforward to model. Significant uncertainty around the timing and sequencing of actions to reduce greenhouse gas emissions make it difficult to estimate the financial implications. Finally, financial institutions do not have all the data they need to link mitigation pathways to client-level financial models.

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Grantham Briefings analyse climate change and environmental research linked to work at Imperial, setting it in the context of national and international policy and the future research agenda. This paper and other publications are available from **www.imperial.ac.uk/grantham/publications**

## Introduction

The ratification of the Paris Agreement[1] in 2015 galvanised international efforts to reduce greenhouse gas (GHG) emissions. An equally important long-term goal of the Agreement was a commitment to "making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development". That same year, then Bank of England governor Mark Carney highlighted the threat of climate change to global financial stability and concluded with a call to "build a virtuous circle of better understanding of tomorrow's risks, better pricing for investors, better decisions by policymakers, and a smoother transition to a lower-carbon economy."[2] In 2018, the Financial Stability Board (FSB) welcomed a report[3] by the Task Force on Climate Related Financial Disclosures (TCFD) and full presentation to the G20 presidency. The G20 have reinforced their commitment to tackling climate change in both the 2019 Osaka Declaration[4] and the 2020 Riyadh Declaration[5]. The TCFD[a] was formed in 2015 to increase transparency of climate-related financial risks. More recently, a growing coalition of central banks, the Network for Greening the Financial System (NGFS) was established in 2017 to "help strengthening the global response required to meet the goals of the Paris agreement and to enhance the role of the financial system to manage risks and to mobilise capital for green and low-carbon investments" (NGFS website[b]). In recent months, a number of leading institutions within the financial sector have made public commitments of their own to support climate financing and reduce their own direct and indirect carbon footprint.

The financial sector needs tools to help it understand and manage the risks and rewards associated with climate change including transition and physical risks. While different agents in the financial world have different specific needs, all would benefit from a common core of information that all can use as a reference. Building this understanding will enable the sector to actively participate in a low-carbon transition both by helping their customers meet their own climate commitments, and by enabling financial flows to lower emission technologies at the appropriate speed and scale. Similarly, financial firms will be less vulnerable to climate related shocks if they can identify, describe, and quantify the channels through which climate-related risks may impact on their balance sheets and earnings.

Scenario analysis is widely seen as a powerful tool that can help the financial sector understand the impact of climate change on current portfolios and future opportunities, and the sector is actively building tools and methods that enable climate scenario analysis to be used in its decision making processes. In doing so, the sector is relying extensively on science-based scenarios, which are of two kinds. First, scenarios of emissions and temperature pathways are aimed at providing insights into the ways in which the world could act to limit increases in temperature. Such transition scenarios generate both risks and opportunities for the financial sector or, broadly speaking, transition risks. Second, scenarios of extreme weather events and of chronic changes in climate patterns can help financial institutions size the physical risk or loss from financing activity that is not sufficiently resilient to such changes.

This paper aims to set out a framework that financial institutions can use to construct, or understand and use, climate transition scenarios. Although it builds on existing work tailored to central banks and regulators, this paper is meant as a guide for commercial financial institutions that wish to incorporate climate concerns in scenario analysis. Instead of recommending particular models or types of scenarios, it focuses on the key concepts that firms need to understand and put together in order to create or choose transition scenarios that result in plausible and credible financial assessments that can be used in business strategy and risk management.

## 2 Climate scenario analysis for the financial sector

Climate change will affect the economy and the financial system through two principal channels which we label as 'climate action' and 'climate impact' (Figure 1), which in turn give rise to transition risks and physical risks, respectively. Climate action is the set of policies, technologies, and behaviours that lower emissions and build resilience. Climate action manifests in the financial system as the risks and opportunities from transition (transition risk) as well as the financing opportunities that arise from building resilience. Climate impact manifests in the financial system as acute and chronic physical risk i.e. the direct and the indirect financial risks arising from changes in climate and weather.

Scenario analysis is a powerful tool that can help financial firms explore the potential implications of climate actions and climate impact[6,7]. In this guide we focus on the former and lay out some of the challenges that arise when creating scenarios that are consistent with alternative actions economic agents may take to limit global average temperature rise in coming decades. Considerable scientific progress has been made in understanding the link between emissions and temperature and a number of large-scale models provide the tools necessary to create alternative scenarios of emissions reduction.

These models integrate representations of technological, biophysical and economic systems and are for this reason called Integrated Assessment Models, or IAMs[8]. While the resulting scenarios provide insights into different configurations of the energy system, industry, land use and agriculture, they need to be extended to create scenarios that consistently describe the associated financial risk and reward conditions[7].

a https://www.fsb-tcfd.org/about/#
b https://www.banque-france.fr/en/financial-stability/international-role/network-greening-financial-system

Macro-financial scenario analysis is routine practice in the financial sector and firms will wish to leverage their existing architecture. The four-step approach typically adopted in standard macro-financial scenario analysis, as shown in Figure 2, is likely to remain unchanged. These steps require firms to create a narrative based on the assessment of an emerging macro-financial risk; quantify the narrative using econometric models to create a plausible set of projections of economic and financial activity consistent with the narrative; use the projections as inputs to models of income and loss at the level of individual portfolios; and finally, aggregate the results to study the impact on earnings and capital. Financial scenarios of climate transition need to work in the same way as standard financial scenarios, by linking narratives to relevant drivers and connecting these to risk factors to gauge the impact on earnings and capital of financial institutions (Figure 2). For a transition scenario, this requires evaluating the impact of mitigation on the financial position of the economic agents involved in the transition and to whom financial firms have exposure, namely sovereigns, corporates and households. This impact can then be translated into the exposure of a specific asset or a portfolio of assets held by the analyst, her employer or a client.

This will not be straightforward however, as financial scenario analysis of climate action presents certain unique challenges[9]:

- **Climate mitigation requires unprecedented structural change:** standard financial scenario analysis is based on macroeconomic and financial risk models that rely on historical experience and the current structure of economic activity. Some of the consequences of such large-scale structural change will be outside our historical experience and will challenge the prevailing worldview. This makes it difficult to assess channels of transmission across economic agents and quantify changes in risk and reward, using existing approaches.
- **Uncertainty:** The relationship between global temperatures outcomes, emissions, the socio-economic response, and technological change is not only complex but also highly uncertain. Understanding the shift in distribution of financial risk across countries, sectors and agents is at the heart of financial scenario analysis but deeply affected by uncertainty over socio-economic outcomes.
- **Model and data limitations:** issues with the availability and quality of required models and data which lead to a high degree of model and data risk.

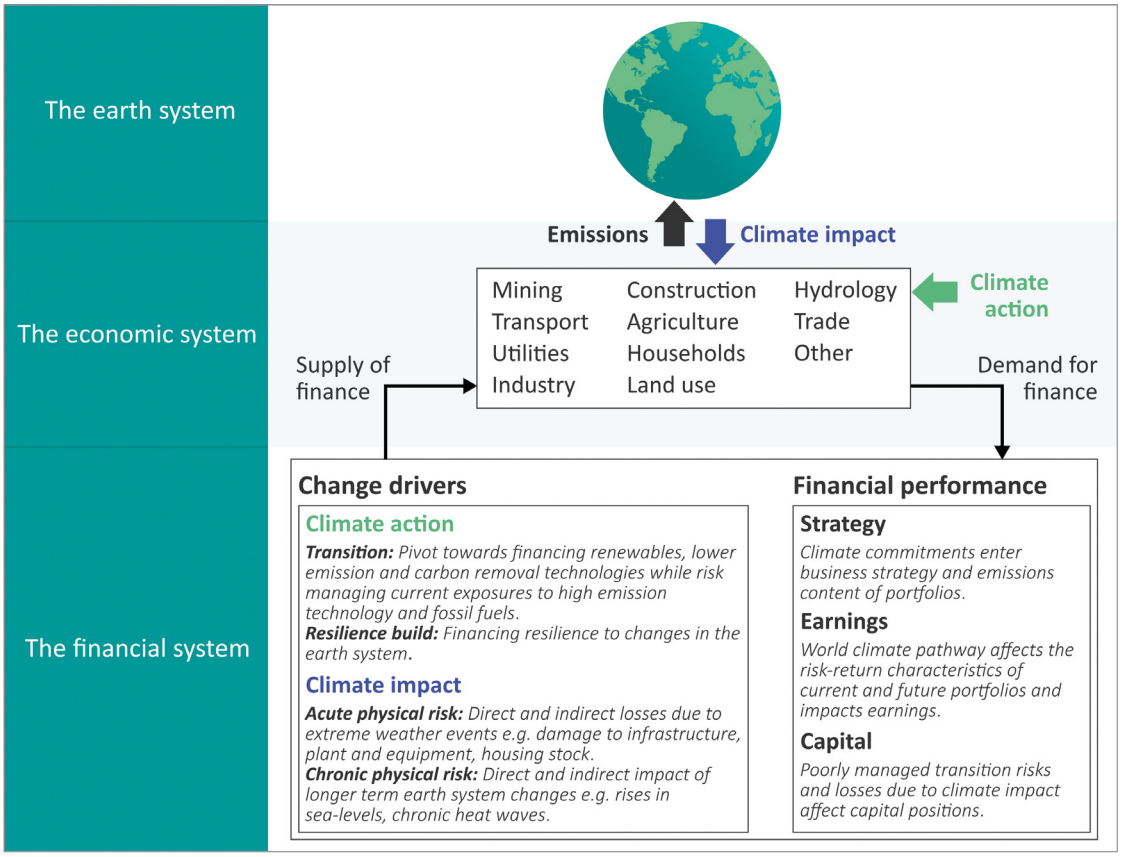



**Figure 1:** Climate change, the economy and the banking system.

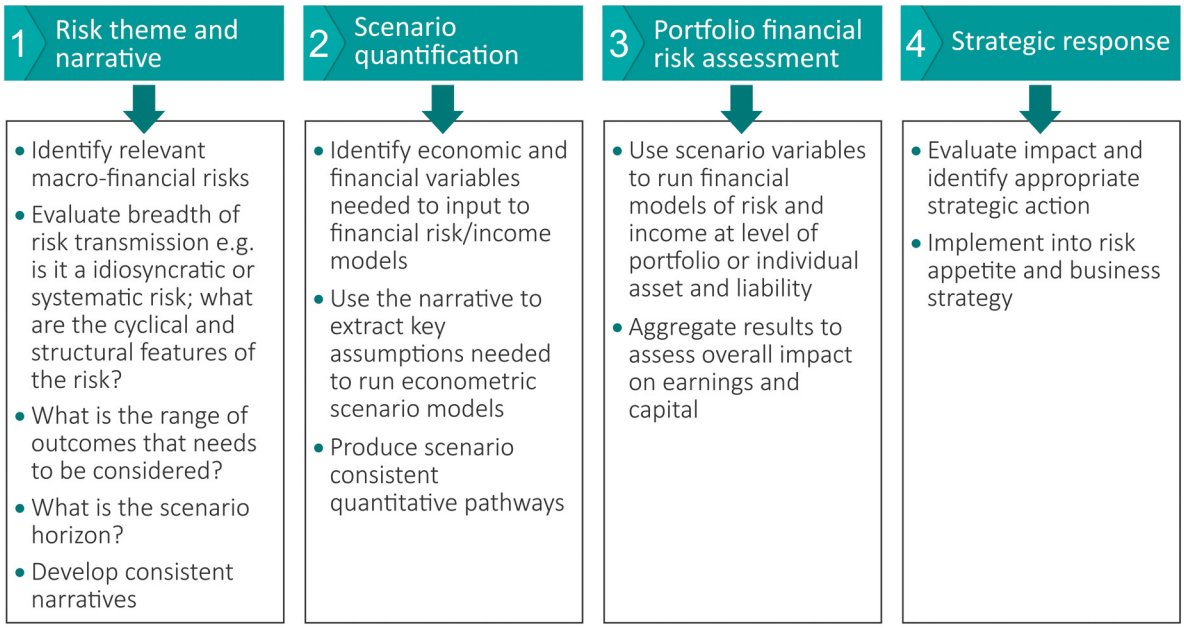



**Figure 2:** Key steps in scenario analysis within financial institutions

Importantly, transition scenarios and pathways, which map out routes to reducing GHG emissions, take the important first step in assessing transition risk by explaining the structural change required in economies through shifts in products, processes and technological structures. However, financial firms have only indirect exposure to products, processes and technologies through the economic agents they finance, and it is the risk perceptions of these agents that financial firms need to understand.

Climate financial scenarios must provide an interface between transition scenarios and pathways and financial risk models and methods to be truly useful to financial firms.

Nonetheless, a financial user faces the daunting task of having to choose between these various scenarios and models and select pathways that align to its understanding of implementation possibilities. It is possible to use IAMs to construct scenarios that fit with a financial user's view of the world, but such scenarios are not necessarily those that achieve an emissions target through the smooth application of a global or even regional carbon price. Financial firms need to develop clear assumptions regarding possible climate actions and use these to select or create climate scenarios that are meaningful for them. Uneven policy implementation across countries and time, technological jumps and barriers, socio economic dynamics including changes in political will and consumer preferences are features that firms will need to evaluate before choosing relevant emissions and technological pathways. Resulting scenarios may be very region-specific or country-specific as a result and may over-shoot or under-shoot a temperature target.

## 2.1 Steps in designing financial transition scenarios

Three well-established IAMs have been used to generate the transition pathways for the recently released NGFS scenarios[6]. The NGFS scenarios were developed to "provide a common starting point for analysing climate risks to the economy and financial system". The initial set consisted of eight scenarios chosen to show a range of lower and higher risk outcomes while embracing the uncertainty inherent in scenario modelling. Additional scenarios are planned for the future. The accompanying *NGFS Guide to Climate Scenario Analysis for Central Banks and Supervisors*[9] identifies four steps in conducting climate financial scenario analysis. Although they target central banks and supervisors, they remain relevant and we adapt and add to them to suit the needs of commercial financial institutions. The steps are:

1. Identify objectives and exposures.
2. Choose climate scenarios.
3. Assess economic and financial impacts
4. Communicating and using results.

For Step 1, a materiality assessment can help determine relevant risk drivers within the scope of the exercise and this applies to commercial banks as well. Clearly identifying relevant risk drivers reduces complexity and helps identify the key variables, regions and risk transmission channels with impact on the target portfolio's holdings.

The task in Step 2 is not as simple as it looks and directly affects the validity of the conclusions that can be drawn from the scenario exercise. One could choose from hundreds of transition scenarios available but choosing between scenarios for the most appropriate ones requires knowledge of how they were built. Conversely, financial firms may choose to build their own bespoke scenarios although this may require overcoming substantial skills and knowledge hurdles and may take time. The steps required in designing bespoke scenarios or choosing from existing ones are described in Section 3.

Step 3 will depend on scope. While central banks may include system-wide risk assessment, commercial banks may prefer to focus on a smaller set of indicators, sectors, asset classes and firms that contribute to risk profiles of holdings they have exposure to. Translating the global model results from sectors down to the level of economic agents requires downscaling techniques and tools, themselves uncertain in their reliability and coverage of risk channels (see below). This is where existing tools have been tested the least, most of them having been developed only very recently. This is also the crucial step in making global climate-economy transition scenarios relevant to financial firms at the granularity required to assess exposure of individual portfolios to transition risks. Bridging the gap from the sector results of IAMs to the operational environment of economic agents, and on to the impacts on individual agents, is a nascent but rapidly evolving field. Section 3.3 and Box 2 explore some recent examples from the literature and highlight steps and challenges inherent in such an effort.

Communicating results (Step 4) appropriately should include not only the key assumptions underpinning them, but also identifying how these assumptions and model structure may explain or even drive the results. The complexity of IAMs makes this quite a challenge, but one that is crucial to ensure results are relevant to the questions posed at the outset. Due diligence on understanding scenarios and models assumptions will also help when choosing from the hundreds of available scenarios (Step 2). This is important to ensure buy-in of key stakeholders such as senior management.

The next section explores some key steps in constructing fit-for-purpose climate-financial scenarios that are useful for commercial banks and asset managers. It also explores how to appropriately use existing scenarios.

## 3 Building fit-for-purpose climate financial scenarios

Scenarios are hypothetical realisations of possible futures that can span a wide range of plausibility, from continuation of business-as-usual trends to radical transformations, some even resembling science fiction[10,11]. There is an infinite number of possible pathways to a low-carbon future and hundreds or thousands of scenarios available in the literature that answer different questions or address specific issues. In assessing transition risk, a financial firm needs to identify the economic agents it has exposure to and then design scenarios that explore how their operating environment changes and how they react to these changes. Expecting a single scenario to address all changes to all agents everywhere is unrealistic. Users of scenarios must therefore narrow down the scope to the granularity required by their material exposures. Clearly defining the objective of the scenario exercise reduces the set of independent variables to a manageable size. What are the key research questions to be addressed? The answer leads to a list of key parameters in specific geographies, sectors, and technologies which together form the scope of the exercise.

Once the scope is defined, properly describing present conditions helps reduce the uncertainty band around future trajectories and helps identify the current trends that have material impacts on future risk drivers. From this starting point, global narratives provide a description of how the world will develop with respect to key indicators of consequence for climate action and its impacts on the global economy and should enshrine a world view consistent with the user's expectations for future developments. Having a self-consistent narrative at the global level also helps users pick from existing scenarios those that fit their view on future developments.

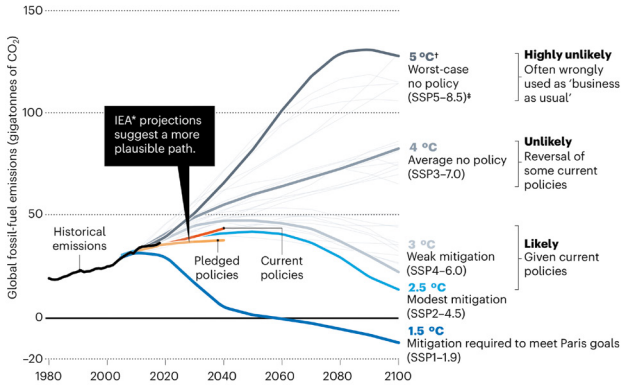
There are two main applications financial firms can use scenarios for: managing climate-financial risk and setting business strategy. The choice of scenarios and the weight associated with each will vary depending on the application. A central *most likely scenario* can be used to benchmark the more extreme, high-impact but less-likely scenarios which, in the case of climate change, could be a *strategic alignment* scenario and a *downside* scenario (see Box 1). An *alignment* scenario may be better suited for business strategy setting since it may better capture the opportunities and challenges to portfolio alignment in a transition, while the *downside* may be more appropriate for risk management. But whether a scenario is strategic alignment or downside, really depends on what it is measured against, that is, the often-called "Reference" or central scenario. Creating or choosing a realistic central scenario is not necessarily easy[12]. The NGFS scenarios[6] do not include a central scenario, so the user must choose one from the existing options: a world with no additional climate policies ("Hot House World"), and two transition scenarios meeting climate mitigation goals, namely an "Orderly" transition scenario with action beginning now, and a "Disorderly" delayed action scenario with considerable disruption (see below for more details). These scenarios describe different future worlds regarding policy implementation, and each has variants that describe different technological developments. Different users will have different views on which of these is the most likely central scenario. The differences across these scenarios form what is called the scenario narrative, and the importance of crafting clear and defensible narratives cannot be understated. Section 3.1 explores the creation and use of narratives.

## Box 1: Types of scenarios

Scenarios need to fit the needs of financial institutions and help them increase their understanding of the opportunities and risks that arise from climate mitigation. Institutions are likely to find that they need to use several scenarios to help them work their way through the uncertainty surrounding climate transition. Not only are there multiple transition pathways to choose from, there are also different policy actions that could potentially accompany each transition pathway. Financial firms will need multiple scenarios to help them separate this mix of global and national ambition, chosen policies and technological possibilities. Scenarios should pick assumptions that are suitably differentiated with an aim to provide insights into different transition paradigms. Scenarios may also be distinguished by purpose, as those used to set strategic direction are likely to have different features to those used by firms to actively manage risk or assess regulatory capital. There are three types of scenarios that are useful to consider in this context:

**The 'most-likely' scenario**

Financial institutions should articulate their expectations of climate mitigation by developing a 'most-likely' scenario. Linking portfolios to the current, most-likely transition scenario helps to assess the degree of portfolio alignment to the current path, as well as the transition opportunity set. The 'most-likely' scenario needs to make a realistic assessment of current, potentially heterogenous, national policy intent and the technological and financial drivers that may serve as enablers or barriers to mitigation. This shifts the focus of the scenario to real-world policy implementation potential and away from pathways that help achieve a temperature target.




Possible futures
Source: Hausfather and Peters (Jan, 2020)[1]

There is a tendency to speak of a 'BAU' (Business as usual) scenario and describe it as one in which global temperatures end the century 4-5 degrees above the pre-industrial level. This approach ignores the climate action already in place and leads to a misleading impression of the size of the gap to a 2- or 1.5-degree target.

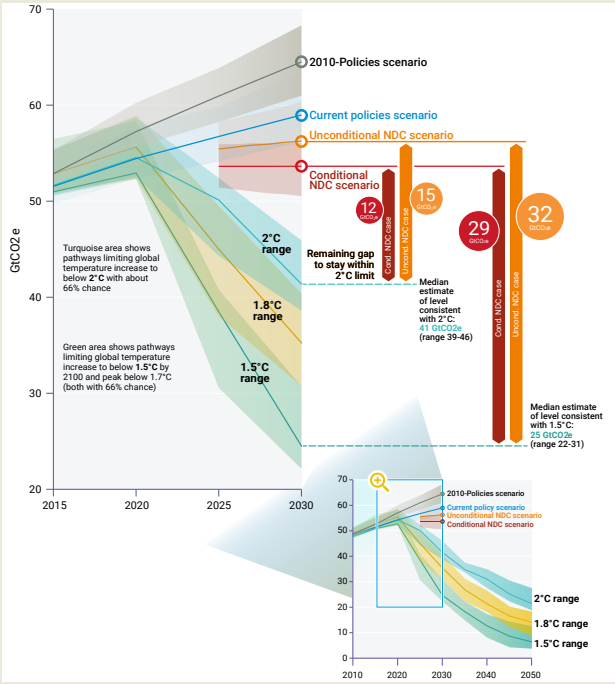
1 https://www.nature.com/articles/d41586-020-00177-3

Scenarios should not confuse a 'most-likely' scenario with a high emissions scenario. Doing so runs the risk of incorrectly calibrating business strategy because of a false understanding of the 'push-off' point for global policy efforts towards greater mitigation.

**Alignment scenarios**

Financial firms are making commitments about decarbonising portfolios or even achieving net-zero targets of their own and developing business plans to increase the volume of climate related financing. Alignment scenarios can help firms understand the emissions profile of their current portfolios and the extent of (mis) alignment with alternative targets. Business plans will be easier to achieve in some scenarios than in others and identifying the range of climate futures that are consistent with business targets will help firms assess the feasibility of their strategic choices. For example, a 1.5 degree scenario with immediate rapid adjustment or a scenario in which only current commitments are maintained may be difficult for firms to achieve. However, firms may find meeting their own climate commitments is easier in a world that actively drives towards a 1.5-degree outcome with an initial overshoot in emissions followed by significant negative emissions in the latter half of this century. Strategic planning may also shift the temporal focus of climate scenarios towards the short term. To achieve 3-to-5-year business targets it is important to understand the pace of near-term climate policy implementation and the heterogeneity across different markets. Such scenarios can also be used to understand the drivers of innovation and understand the financing needs of sectors in transition. Financial firms need to assess their strategy against alternative scenarios and identify the range of scenarios that enable them to meet their strategy. Source: UNEP (2020)[41]

**Scenarios that align best to a firm's strategy**



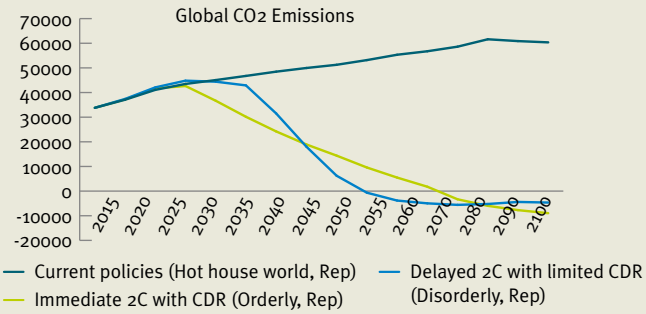

A range of emissions pathways based on current national policies and commitments

**Downside scenarios**

There are a number of different ways in which climate mitigation can result in negative economic and financial outcomes. The NGFS provides an example of a downside scenario in which deep and abrupt mitigation may create significant transition risk. Disorderly financial and economic outcomes may also be the result of geo-political and socio-economic factors related to the implementation of climate policy, which create barriers in trade, financial and labour markets. This is an underexplored research topic, partly because scenarios of socio-economic and geopolitical risks can be subjective and may reflect the user's own views rather than unbiased calibration. Ultimately, to aid practical risk management, downside scenarios need to explore relevant, real-world, plausible risk themes.

2 Data available from https://data.ene.iiasa.ac.at/ngfs/#/workspaces
3 REMIND-MAgPIE scenarios shown for illustrative purposes.

**Disorderly adjustment scenarios[3]**




Of the different NGFS scenarios, the 'Disorderly' adjustment scenario is likely to result in a high degree of transition risk, given the sharp and abrupt adjustment required to limit the increase in temperature to 2C. The other two scenarios shown have different degrees of transition risk. The 'hothouse' world has very little transition risk (but results in much greater physical risk) while the Orderly scenario is likely to have more limited transition risk than the Disorderly scenario, given the more gentle adjustment path.
Source: NGFS[2]

Evaluating impacts of mitigation on economic agents is not a simple exercise. These impacts manifest themselves across scales, from the global to the local, and across domains (socio-political, technological, biophysical, and economic). To provide enough information on how a transition impacts on agents' direct operating environment and how they in turn react to changes, climate-financial scenarios need to consistently and explicitly address the links across these scales. IAMs are useful here as they represent key parameters in each of these domains which allows for the assessment of trade-offs (and synergies) across them. For example, it is possible to assess the extent to which achieving decarbonisation by means of some technological alternative (say large-scale bioenergy deployment) may impact on other domains such as the biophysical (via land use dynamics and biodiversity) or socio-political (e.g trade of agricultural commodities). But since IAM outputs stop at the sector level, and sometimes at the regional level, considerable effort needs to be dedicated to expanding scenarios to the necessary level of granularity needed to fit downstream models of financial income and loss (Section 3.3).

Developing scenarios along these lines requires cross-disciplinary expertise and firms should attempt to build such capacity in-house to the extent possible since this allows for greater control and transparency of assumptions and parameters. Should that be beyond a firm's capacity, it is also possible to use existing scenarios and tools to draw insights on climate financial risks and opportunities. In this case, users need to ensure that the candidate scenarios are fit for the purpose at hand by dissecting the assumptions embedded in the scenario design and structures of the models used. Given the complexity and limited transparency of many existing scenarios and tools, the latter approach may be as, or more, challenging than the former.

The effort is justified since the user will require scenarios that have plausible assumptions that can be explained to different audiences. Users will also wish to track real world progress against scenarios and understand when scenario assumptions are no longer defensible. For this, there is a need to unpick scenarios, understand assumptions regardless of whether one utilises available scenarios without any modification or whether one designs bespoke scenarios.

The following sections describe the basic elements of scenario design. Figure 3 describes the elements of scenario design and the steps to follow when developing climate-financial scenarios, pointing to the next sections where each step is described in more detail. Understanding and applying this flow is also useful for those intending to use existing scenarios as it helps choosing appropriate ones to answer relevant questions.

## 3.1 Creating Scenario Narratives

To explain how each scenario differs from the next, it is useful to create narratives or storylines that describe how each of the relevant drivers develops. Whether users create bespoke scenarios or consider which scenario(s) to use, the scenario narrative ensures convergence between the user's worldview and the scenario assumptions. Therefore, good narratives should be developed in either case. Good examples of scenario narratives are those used for the Shared Socioeconomic Pathways, or SSPs[13], and the extensions of SSP2 in the NGFS scenarios[6].

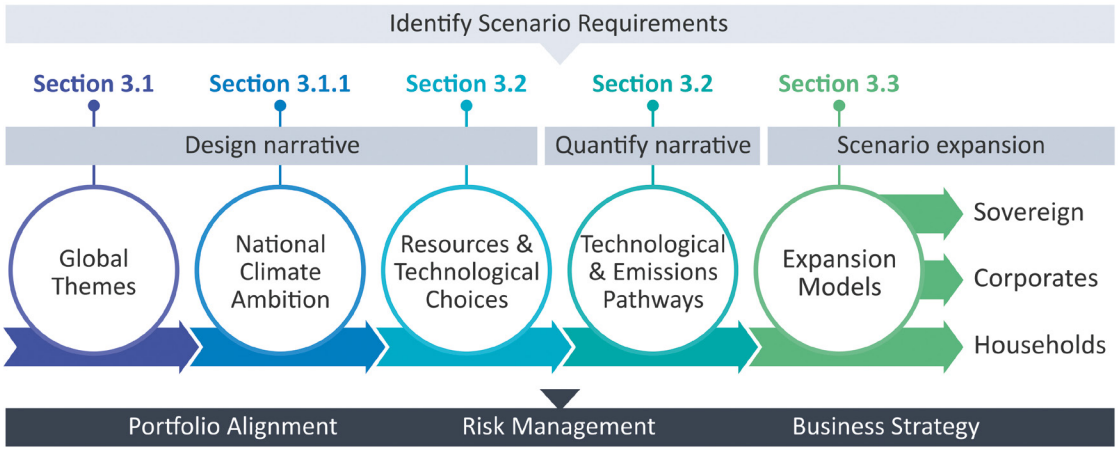



**Figure 3:** Steps in designing bespoke scenarios or using existing ones with links to the relevant sections in this paper.

There are various aspects narratives should address:

- The development of society and the economy, or so-called **socio-economic developments**, will have a large impact on the direction of climate change action, and therefore the pace and scale of transition risk. The pace of the transition defines the rate of change in technological preference and in the level of risk associated with certain financial positions. Specific narratives need to be built that describe expected or projected future developments in the financial sector, and which lay out the financial implications for the long-run socioeconomic narratives.
- **Technological change** affects the relative costs of various low-carbon alternatives facilitating the transition, but also potentially rendering incumbent technologies obsolete, leading to stranded assets. It can also create whole new markets. It can lead to both risks and opportunities with direct consequences for the performance of portfolios.
- The **geographical scope**: Financial institutions have exposures in specific countries. Scenarios must reflect this exposure, and also have the right degree of granularity to be sufficiently informative. It is fundamental to develop views on how a country's future unfolds along dimensions of policy and regulation, available technological alternatives, and its insertion into the global economy.
- The **temporal scale** is important to consider at the outset including both the timing of the mitigation actions, or policy shocks, and also the timeframe over which the scenarios are reporting. The long-term world view required to consider climate change risks is at odds with the comparatively short time horizons predominant in financial analysis. The different timing of policy shocks is the main parameter used to differentiate among the NGFS mitigation scenarios, namely the early action versus the delayed action scenario. Scenarios should capture relevant future trajectories and can then work backwards to identify short-term trends that will become dominant in each alternative future. These short-term trends have financial consequences now and to understand them a long-term view is required.

Climate change presents a global co-ordination problem and the level of global commitment will play a key part in conditioning national climate strategy and financial response. Commitment to climate action comes in many flavours and varies across geographical scales that are interconnected. Properly setting the **global** backdrop helps narrow down the range of possible outcomes to choose from regarding how the storylines in the narratives may evolve. Climate action can be coordinated or fragmented, involve early or delayed action, and each combination reflects distinct worldviews implying various levels of challenges and present different types of financial risk.

Different policy contexts merit different choices of appropriate central scenarios[12]. For geographies that have binding legislation for emissions reduction (e.g. UK net-zero targets) there is arguably no need for a no-policy baseline, assuming the region in question has strong institutions expected to comply with legislation. In other regions the central scenario may be instead based on current trends, like a combination of current policies and technological outlook for example. Likewise, different technological outlooks should guide the choice of the reference scenario with, for example, higher share of renewables if cost reductions are expected to continue. Counter to what some may expect, a considerable amount of transition risk exists in scenarios that do not meet Paris Agreement temperature goals. Globally, a most-likely climate financial scenario may differ from scenarios that achieve the objectives of the Paris Agreement, which are in essence target-seeking scenarios meeting normative temperature and emissions reduction targets. The key question to ask: is the world on track to limiting temperature rise to 2°C? And if not, then where are we headed (see Box 1)

Choosing a reference scenario that is defensible and realistic provides a robust benchmark against which to measure the impacts of the alternative (policy) scenarios. That is, to assess the financial risk and reward associated with climate action, alternative scenarios must consider the policies, mitigation efforts, and macro-financial implications of transition against a backdrop of assumed socioeconomic and technological

development that are realistically represented in the reference scenarios. Because there is much uncertainty about future policy environment, technological and behavioural change, and socioeconomic developments, scenarios exploring alternative evolutions of these drivers imply different types of challenges to and enablers of climate action. A world that embraces sustainable lifestyles (plant-based diets, active mobility etc) may face fewer challenges to decarbonise than one where carbon-intensive lifestyles dominate. Such considerations need to be in the reference if they are not the result of the applied policy, technology or behavioural shocks. Narratives should explicitly address these issues.

The NGFS scenarios build on the Shared Socioeconomic Pathways or SSPs[14,15] developed as part of the work of the Intergovernmental Panel on Climate Change (IPCC) to provide a common framework that could be used by the various research communities conducting climate research (mitigation, adaptation, impacts, atmospheric). The SSPs are good examples of socioeconomic scenarios covering a broad range of plausible global futures in the absence of climate policy intervention. The current NGFS scenarios were based on the "middle of the road" SSP (SSP2) in which the world develops along recent socioeconomic and technological trends that do not deviate markedly from historical patterns. The SSP2 narrative describes a world in which "[d]evelopment and income growth proceeds unevenly [and] … [g]lobally connected markets function imperfectly", while "[t]echnological development proceeds apace, but without fundamental breakthroughs"[13]. In summary,

> *SSP2 does not imply a simple extrapolation of recent experience, but rather a development pathway that is consistent with typical patterns of historical experience observed over the past century. For example, emerging economies grow relatively quickly and then slow as incomes reach higher levels, the demographic transition occurs at average rates as societies develop, and technological progress continues without major slowdowns or accelerations. Thus it is a dynamic pathway, yet one in which future changes in various elements of the narrative are consistent with middle of the road expectations, rather than falling near the upper or lower bounds of possible outcomes. (O'Neill et al. 2017[13])*

In this regard, although the NGFS scenarios lack a central case, they are built on middle-of-the-road expectations resulting in a world that is not near the frontiers of plausibility. Using this world as a starting point, the NGFS scenarios differ from each other in how climate policy is assumed to evolve and on certain technological availability assumptions[6]. The climate policy variants are the central cases for each of the main NGFS scenario families:

- Hot House World: low climate action leads to high temperature increases and results in "strongly increased exposure to physical risks".
- Orderly: Early (coordinated) and ambitious action to a net-zero CO2 economy
- Disorderly: Delayed (fragmented) "[a]ction that is late, disruptive, sudden and/or unanticipated"

These are examples of global narratives for climate policy evolution. Meant to be a set of touchstone scenarios for a global transition, these follow a common global narrative, but are silent on region- and country-specific narratives and may not represent national specificities of relevance[c].

Because financial firms have exposure to specific assets in specific geographies, financial scenarios must have adequate regional granularity to provide insights into how key geographies will develop over time. For example, national policies and the degree to which country risk may change need to be accounted for. These, in turn, depend on global conditions, and a consistent storyline linking the national and global scales helps maintain internal realism of the scenarios. Models are then used to provide a quantitative evolution for key parameters, producing a pathway that includes relevant variables like greenhouse gas emissions, demand for commodities, or capacity and utilisation of technologies. More specific narratives and modelling at national scales helps capture regional specificities as described in Section 3.2.

### 3.1.1 Connecting global and national climate ambition

Once a global world view is clearly delineated, national narratives can be developed to explore country-specific contexts. Importantly, countries' alignments to global narratives can vary, with profound implications for financial risk drivers, and scenario narratives should capture these interactions. In this way it is possible to weave country narratives that span a wide range of alignment with the global narrative. These country narratives need to describe what a transition may look like in the country in question and should begin with the current situation and trends. While global scenarios may provide results for individual countries and regions (NGFS and SSP scenarios do), they may not include country-specific narrative elements with high impact on the future development of that country. For instance, national energy systems often have specificities that may not be captured by the global portfolio of technological options available in models as is the case, for example, for the Brazilian bioenergy sector[16]. An example for an expanded SSP for Japan[17] was motivated by the fact that Japan does not necessarily align with the socioeconomic assumptions in the global scenarios.

The extent to which transition risk is increased or decreased (in a particular country) depends on factors governing the speed, depth and scope of the changes to current trends within the horizon of financial actors. These are, in turn, determined by drivers of public policy adoption and demand for goods and services, the size of the mitigation challenge, financial ability, and the balance of barriers to and enablers of change.

c More detailed national representations will be explored in future versions of NGFS scenarios.

At the national level, these factors may or may not align with the global narrative. Many barriers and enablers of change are subject to political economy concerns with substantial implications for financial outcomes. For example:

- **National policy packages on climate** need to be explored, and how they relate to the global narrative. Climate policy could be limited to policies that directly target emissions or could also include policies that indirectly impact emissions. The binding carbon budgets in the UK are direct climate policy, whilst any energy policies aimed at reducing energy consumption, industrial and social subsidies which may bolster carbon-intensive activities etc are indirect, but relevant. Direct climate policies are price and quantity restrictions on GHG emissions enacted by governments acting individually or in collaboration with each other. Users should choose definitions that meet their specific objectives.
- A narrative of **global fragmented climate action** in which some regions take climate action alone should include what actions these regions would take, if any, to protect their economic competitiveness and prevent carbon leakage. For example, carbon border adjustment taxes (BATs) would potentially lead to supply chain disruptions, making some sectors or firms more vulnerable. Others may be exposed to a tit-for-tat reaction from disgruntled trade partners, and others still may actually benefit.
- On the other hand, while a **globally coordinated transition** to a low-carbon economy may ease the tensions across regions, it is likely to disadvantage fossil-fuel exporting countries. A drop in the price of oil could also put pressure on sovereign debt assets of countries that support national oil companies or are dependent on fossil resource rents (Box 3). Conversely, countries with large renewable resources and the means to exploit them may actually benefit.
- A **country's risk profile** will be affected by its access to alternative revenue streams. While Saudi Arabia may tap into its sovereign fund to develop its vast solar energy potential to compensate for declining oil demand in a transition, other oil-dependent countries like Nigeria may have a harder time doing so.
- **Technological change** can introduce options for decarbonisation or alternative revenue streams and may affect other aspects of the national storylines. For example, falling costs of solar panels or the rapid development of competitive solar power-to-fuel routes help drive up the value of Saudi solar potential in the global energy market. In addition, falling costs of solar and wind are eroding the competitiveness of coal-fired power generation forcing many of the less efficient, non-economic power plants to be shut down e.g. in India[18]. The rate of cost reduction for low-carbon technologies and their potential availability also help determine the challenges and opportunities for the financial sector. Availability of some key technologies like carbon capture and storage (CCS) contribute to the resilience of fossil-fuelled activities during a transition. One of the NGFS scenario variants explores what happens if carbon dioxide removal (CDR) technologies are less available.

Narratives should be the touchstone used to gauge the relevance of any candidate scenario. For example, if the user's technological change narrative assumes CDR technologies to not be widely available, a scenario deploying lots of CDR is not a useful one to consider since it falls outside the user's plausibility bounds. On the socioeconomic side, a scenario projecting labour productivity to grow at very high levels should be excluded if the user's socioeconomic narrative assumes the opposite. A scenario user with exposure to a national oil company will need to have a view on the extent of sovereign support required in a transition. This is why it is fundamental to have clear narratives that detail the user's worldview, that is, how the user sees the future development of key scenario parameters both globally and nationally.

All narrative elements listed up to this point have to do more with techno-economic transition scenarios (like those in IPCC reports) than with climate-financial scenarios. Most techno-economic scenarios do not include financial narrative elements because the financial sector is not represented in them, nor in the models used[19–21]. There is a push to include financial narratives in climate-economy scenarios[21] and some are starting to emerge (e.g. Allen et al[20]). In addition to including the financial sector, narratives can be broadened to include the wider architecture of the political economy that might be needed to ensure transition in scenarios, and which would influence financial outcomes. This involves developing pathway-consistent views of the trade, investment, fiscal and financial architecture in scenarios and weaving these into narratives.

For example, the financial architecture and the political economy of SSP1 are likely to differ considerably from that of SSP5 and will have an influence on investment flows, risk and reward. These future financial sector trajectories gradually diverge from a common starting point in the present, so narrative development starts with an assessment of countries'

initial economic and financial strengths and vulnerabilities. These 'initial conditions' align with the risks facing financial firms today and should draw early attention to features that need to be factored into the design of scenarios. Alternative future storylines can then emanate from this starting point and be built consistently with the broader social backdrop chosen. This applies not just to emerging economies with the potential for structural change in both economic institutions and financial markets as they grow and deepen their economies. It is also important for advanced economies as they undertake a significant pivot towards lower emissions. An assessment of climate transition risk at a national level should at least consider the following and how these may evolve in the future:

- *Economic strength:* the ability of a country to sustain trends in economic growth and welfare.
- *Financial, trade and investment architecture:* the willingness and ability to implement change in markets and systems to support transition.
- *Institutional quality:* an assessment of the capacity of a country's legal and political systems to adapt to transition needs.
- *Exposure to global transition risks:* the degree of global interconnectedness and the impact on transition e.g. via international supply chains, R&D linkages, or trade relations.

The country narrative needs to provide a view on the evolution of any barriers to or enablers of change, especially those affecting financial outcomes, and how they may deviate from current trends. For example, the emergence of a green bond market is more likely to occur in economies with an already mature financial market as, in many cases, barriers to emergence of a green bond market can be traced back to structural barriers that also block the evolution of conventional financial markets. In addition to structural barriers like uncertain political, macroeconomic and regulatory environments, there may be barriers to investment flows that are specific to low-carbon projects such as technology risk, higher upfront costs, and the lack of a track record in financing such projects or of a domestic industrial base[22].

Other factors that may bear on a country's climate ambition or engagement with the transition include its resource potentials and educational attainment (skills) of its population. Educational attainment impacts labour productivity rates and may constrain deployment of skills-intensive technologies. Such factors are often considered drivers of climate-economy scenarios as, for example, educational attainment in the SSPs[23]. Climate-financial scenarios need to capture, and users need to understand, the evolution of these relevant parameters and how they may enable or constrain the evolution of financial markets in individual geographies.

## 3.2 Quantifying the narratives

Narratives are plain language descriptions of future developments in each scenario. To be useful in financial decision making, these cognitive-linguistic roadmaps must be translated into numerical estimates of the changes in key parameters. The quantification of the scenario narratives requires some form of numerical models that describe the systems involved (energy, land use, economy) in a minimum level of detail to appropriately answer the questions posed by the user. What is deemed appropriate is part of vetting of scenarios as described earlier, including due diligence on model risk and data uncertainty. The models can range from structurally simple models done in spreadsheets to highly complex mathematical models involving hundreds of thousands of lines of code. IAMs fall under the latter category and are the workhorses of transition scenario development. While highly complex, they are not without their shortcomings[24–27] which, along with their strengths[8,28,29], must be clearly understood by users of these tools and their outputs.

IAMs like the ones used to produce the NGFS scenarios have been used in hundreds of peer-reviewed academic studies on climate change mitigation. They feature in several assessment reports, including those from the Intergovernmental Panel on Climate Change (IPCC), and have a long tradition of informing climate policy design[30]. They capture key relationships between natural (atmosphere, biosphere, water and nutrient cycles) and human systems (economic activities, energy, land use and agriculture). As such, they are useful in assessing implications of a transition at the systems level, across regions and sectors. That is, they provide a lens through which to identify and understand key sectoral and geographical interlinkages that may i) hinder or facilitate the transition, and ii) lead to co-benefits or adverse side effects. Some of these interlinkages, be they synergies or trade-offs, may have been unforeseen since they may occur in different sectors. For example, electric vehicles can only help decarbonise transport if the electricity supply is low carbon; bioenergy is only carbon neutral if it does not lead to land use change (deforestation). These dynamics are captured in IAMs.

However, there is a gap between what IAMs deliver as output and the inputs required by financial risk methods and tools, and this gap needs to be bridged. Techno-economic models, including IAMs, tend to only provide aggregated results at the sector level and lack granularity at the economic agent level. Additional tools are required to downscale from the sectoral outputs of IAMs to the level of economic agents that the financial sector has exposure to. The bridging of this gap is a hot topic in climate financial research, and it is evolving fast (see for example Allen et al[20]; Battiston and Monasterolo[31]; UNEP FI[7]). This type of scenario expansion is further explored in Section 3.3.

It is also a space that many financials, consultancies, and academics are trying to fill with a proliferation of new tools in recent years. Many use outputs from IAMs as inputs to their climate-related financial risk tools to bridge the gap from IAM sector results to agent level dynamics. Different tools use different methods, to varying degrees of transparency, coverage and reliability (Bingler & Senni[38]), so users should be cautious about applying the results from these tools in strategic decision making involving large sums of money. The methodology and structure of any tool should be fully transparent to the user.

The shortcomings of these tools can compound some of the shortcomings of IAMs, contributing to increased model risk of the whole framework. Global models like IAMs tend to aggregate countries into regions, so that many countries may not be represented in global scenarios and it may be necessary to downscale the global results to the national level, for example, by using national models[20]. Even countries represented in IAMs often suffer from sectoral representation not fully aligned with national realities in important indicators. This may be particularly the case for countries that have unique features that cannot be captured at the resolution of a global modelling framework. For example, global models tend to have limited regional differentiation of energy technologies, which means existing global climate transition scenarios may overlook regional energy transition dynamics[16]. The results at the national or regional level from global IAMs can vary widely in some key indicators[32] meaning they can only provide limited insights into country-level dynamics[16,33]. Linking to national models can help address this issue (see for example Schaeffer et al[32]; Koberle et al[34].

Another relevant aspect of IAMs is that they do not consider unforeseen events like a radical technological innovation or an extreme climatic event. The average economic impacts attributed to climate change by models does not consider extreme climatic events in the tail end of the probability distribution (tail events), meaning they may be underestimating the risk of the physical impacts of climate change. Conversely, disruptive technological innovation may render whole sectors unviable as exemplified by the pressure on coal power generation originating from the cost reductions in solar PV or the advent of shale gas in the US. These were not foreseen and therefore not considered in earlier scenarios. Likewise, current scenarios were built on model structures that do not (yet) include some promising low-carbon technology options like synthetic fuels made from curtailed renewable electricity and $CO_2$ captured from the air.

Finally, countries' domestic priorities probably imply non-alignment with the trajectories resulting from global cost-minimisation exercises like those resulting from most current IAMs. There are many ways to allocate the remaining emissions budget among the countries, each leading to varying degrees of effort sharing and fairness[35]. Remaining emissions allocation across countries that result from global cost-optimal pathways are generally not aligned with national priorities, especially for developing economies. Alternative allocation criteria (other than global cost-optimal) such as Greenhouse gas Development Rights (GDR), or Per Capita Convergence (PCC) lead to much larger emissions allocations to developing countries[36]. For a country like India, for example, drastic coal phase out scenarios may not play out if the country decides a GDR or PCC approach is a fairer allocation of effort. Developed countries tend to have larger budgets under cost optimal allocations and much smaller budgets under alternative fairer approaches. Because the Paris Agreement relies on voluntary pledges from national governments, the likelihood that a cost-optimal trajectory towards well-below 2 degrees will emerge from them is debatable.

These limitations must be explicitly considered when drawing on IAM results to make financial strategy decisions as they add to model risk. That is why careful vetting of scenarios employed is fundamental and should include an assessment of the scenarios for their relevance at the country, sector and technology levels. Still, although not perfect, IAMs can be extremely useful when used properly. It is important then, to not simply pick scenarios from IAMs solely based on temperature outcomes or emissions and carbon price trajectories. The narratives and assumptions used to build the mitigation pathway must align with the user's own outlook and research questions.

## 3.3 Scenario Expansion

Most financial users will wish climate scenarios to quantify financial risk and reward. This shift in focus to financial outcomes suggests that IAMs on their own are unlikely to provide a rich enough characterisation of economic behaviour to enable a direct assessment of financial risk and opportunity.

Users will require a set of macro-financial drivers that correlate with the financial risk profile of economic agents in their portfolios. If these drivers are not available as the standard output of an IAM, users will have to resort to additional models and methods to obtain consistent projections. We refer to this process as scenario expansion and is a vital next step in creating climate financial transition scenarios.

As Figure 4 shows, for the three principal categories of portfolios held by financial firms, namely sovereigns, corporates and households, assessing climate risk in portfolios requires linking policy and technological choices through to the impact on the operating and financial conditions of each class of agents. An expanded scenario has to provide sufficient economic characterisation to enable users to measure the impact of climate policy and technological choices on the operating and financial conditions of three different categories of economic agents – sovereigns, corporates and households. The extent of expansion required will depend on the scope of financial portfolios and the macro-financial drivers of risk and reward.

The macro-financial drivers required to enable financial risk assessment will depend on the class of agent. For sovereigns, the output of a top down IAM assessment needs to be

translated into the impact on different factors including fiscal positions and sovereign risk premia. For corporates, scenarios need to detail the sectoral strategy in response to technological switching anticipated in the scenario. For households, it will be necessary to build out the impact of corporate strategies on patterns of employment, consumption, prices and savings. Current versions of IAMs provide aggregate levels and timing of investments in scenarios. Built on cost-minimization paradigms, most tend to be silent on profits, debt and equity valuations. In addition, IAMs have incomplete sectoral and country coverage. Expansion to cover all portfolios and relevant aspects of macro-financial risk is likely to require users to extend their scenarios to capture the sectors and economic structures not typically represented in an IAM. For example, IAMs generally do not represent the government sector richly enough, and also may not distinguish between up, mid and downstream oil sectors, and so on.

There is a growing literature with examples of how to bridge this gap for financial stability stress tests under climate change. Bolton et al[37] provide a good summary while Bingler & Senni[38] assess[16] existing tools used to provide firm-level risk metrics that can be used as input for standard risk models. Some tools rely on pre-built scenarios, like those from the International Energy Agency (IEA) or from IAMs, and assess firms' exposure to transition risk via their emissions profile or adaptive capacity using (often) proprietary databases, or through network effects or input-output tables, just to cite a few examples (see Bolton et al.[37], p.38). Monasterolo[39] provides a detailed roadmap for including climate risks into modelling frameworks and describes the application of the CLIMAFIN framework to IAM results to derive the probability of default (PD) and Climate Spread metrics. UNEP FI[7] describes the framework used for an early exercise in which several banks participated.

Allen et al[20] provide an example of an expansion exercise for France by linking several models to the IAM results of NGFS scenarios and providing financial risk information at the sub-sector level via a financial rating model that addresses the "infra-sectoral heterogeneity" across firms. Because the IAMs include France within the EU region, a macroeconomic model (NiGEM) was used to downscale the EU regional macroeconomic impacts to France and to provide the macroeconomic variables not provided by the NGFS models that are necessary for a financial risk assessment exercise. Such an approach may be appropriate for a country like France, a wealthy, developed country with mature financial markets and strong institutions with a significant historical emissions responsibility, which means it may well follow an emissions pathway aligned with a cost-optimal global scenario. Other countries may differ.

| | Sovereigns | Corporates | Households |
|---|---|---|---|
| Policy conditions and technological choices | Climate ambition: targets and challenges.<br>Commitment to domestic institutional capacity building e.g. tax reform, changes to monetary policy.<br>Trade and investment policy. | Assessment of decarbonisation possibilities and costs.<br>Industry specific measures including tax incentives and risk guarantees. | Decarbonisation possibilities and costs.<br>Tax incentives and subsidies. |
| Operating conditions | Fiscal impact of climate and supporting policies, differentiating between cyclical and structural changes in fiscal positions of governments. | The impact of climate and supporting policies on the profitability, debt service capacity and dividend policies of industry sectors during transition.<br>Volume, prices and costs of goods produced, using existing technologies and production processes.<br>Volume, prices and costs of goods produced, using lower emissions technologies and production processes. | Transition impact on employment trends.<br>Impact of climate policies on real disposable income.<br>Additional encumbered income due to transition commitments. |
| Financial conditions | Financing needs arising from a change in fiscal position.<br>Sovereign risk premium for participation in financing transition.<br>Crystallisation of contingent liabilities due to sovereign support of fossil fuel and emission intensive industries. | Impact of stranded assets and capital on existing debt and equity.<br>Additional financing needs to meet decarbonisation targets. | Capital expenditure required to reduce household emissions e.g. investment in housing and vehicles.<br>Wealth effects e.g. impact on house prices and savings rates. |

**Figure 4:** Climate change, the economy and the banking system.

## Box 2: Surviving a transition

Transition scenarios from IAMs project deep structural changes in how electricity is both produced and consumed. IAMs project decarbonisation of electricity through a shift to renewables to provide low-carbon electrification of end-use energy services like heating, transportation and industry. This implies significant challenges to the traditionally fossil fuel dominated utility industry, exposing it to high levels of transition risk as it will experience direct consequences of an energy transition. Responsible for about 40% of global emissions (IEA 2017) this sector is exposed to any action to reduce carbon dioxide emissions[42]. Because of the long lifetime of power plants, fossil-based power generation assets face significant risk of stranding in a transition. Transition scenarios vary in two key parameters impacting the resilience of power generation assets: firstly the timing and secondly the rate of fossil assets retirement. These in turn depends on the implementation and stringency of climate policy[43].

Transition risk (of portfolios or individual firms) is determined by the utility's ability to navigate, adapt and eventually survive the transition. This ability is determined by the firm's financial health and capacity to invest in alternative power generation technologies, the age of its fossil fuel assets, and the price of electricity the market can bear. Therefore, assessing transition risk of such firms requires detailed individual firm-level data and electricity price projections in each scenario. However, IAMs provide mostly cost-based modelling, and price projections tend to be limited in their ability to capture the full range of market dynamics shaping price formation in the real world[44].

Transition scenarios to inform investment decisions in utilities will need to capture the ability of firms to transition to a generation capacity mix that is aligned with required caps on greenhouse gas emissions. This requires linking IAM outputs with more granular firm-level modelling that captures balance sheet dynamics and the firm's ability to shift to a low-carbon production base. Cormack et al[45] integrate an IAM (JRC-POLES) with a corporate model that captures the adaptive capacity of a set of companies to meet energy transition requirements and illustrate its use by evaluating the risk of different scenarios to major EU27+2[i] utility companies.

Results show that in a 2-degrees scenario, companies with high shares of renewables display higher equity returns on average (Figure 5) while their credit ratings improve over time (Figure 6), in contrast with the fossil fuel-dominated companies. While the majority of utility companies in this study manage to survive the transition, the few defaults confirm that capital structure constraints play a key role in the ability to adapt to the new technology demands. Importantly, this suggests that several EU utilities with current fossil generation share above 75% may not only survive the transition to a 2-degree consistent energy system, but they may do so while generating positive returns. This points to the need to go beyond simplistic views that firms with high carbon intensity of operations are doomed to fail.

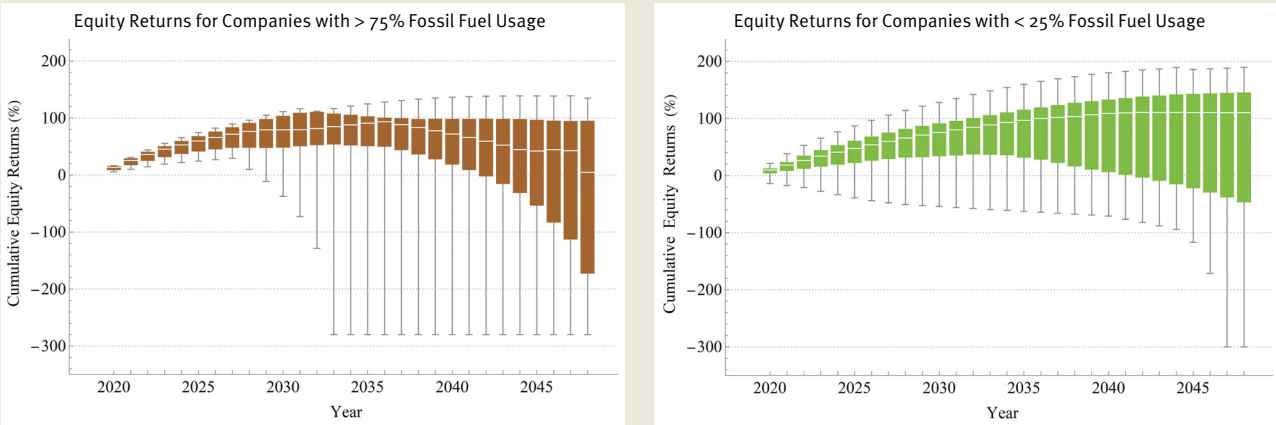
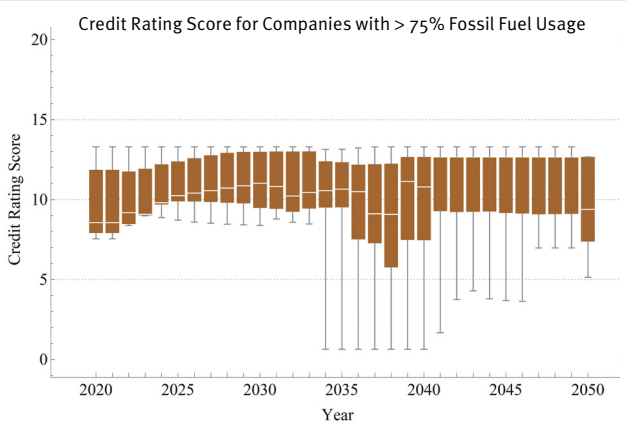



*Figure 5: Box-Whisker Plot of equity returns migration from 2020 to 2050 for Fossil Fuel Dominated (top) and "Green" Companies (bottom). Source: Cormack et al 2020.*

i EU27+UK+Norway



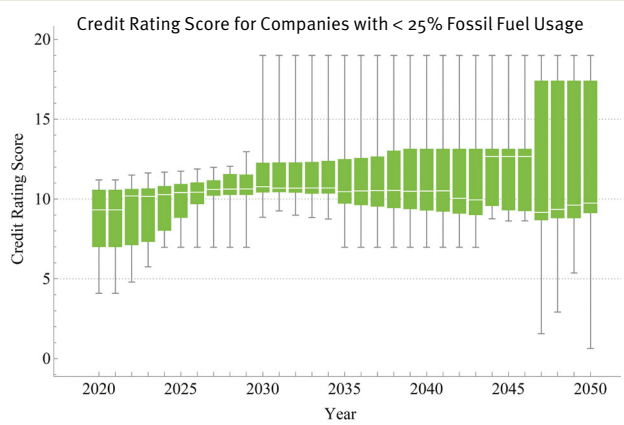




*Figure 6: Box-Whisker Plot of credit ratings (the higher the number the better the credit rating) from 2020 to 2050 for Fossil Fuel Dominated (top) and "Green" Companies (bottom). Source: Cormack et al 2020.*

The energy system and economic representations in IAMs provide a technologically efficient pathway for emissions reduction and do not capture real-world economic issues such as lumpy, irreversible investment decisions, feed-back loops across the macro-financial system and the possibility of sudden changes in financial market risk-aversion. Three boxes explore these issues.

Box 2 describes an example (Cormack et al[40]) of how to use the output of an IAM to make assessments of credit risk in the EU power generation sector. Understanding the credit risk of an individual corporate in the power sector, in principle, requires knowledge of a firm's financial position and its strategy, plant-level asset data, in addition to scenario specific prices. Cormack et al[40] present a methodology that allows the output of an IAM to be directly linked to a model of corporate risk, thereby enabling firm level projections of balance sheets, generation capacity and credit risk to be made. It is important to note that transition scenarios project deep structural change in how electricity is both produced and consumed and capturing such change requires going beyond the conventional indicators of the macro-financial cycle typically used to measure credit risk such as GDP, unemployment or an index of financial asset prices. The authors use projected installed capacity and power generation per technology, capital cost and O&M expenditures from an IAM as constraints for the corporate model. The results show that large electric utilities in Europe fare differently in a transition depending on the carbon intensity of their operations, but carbon intensity alone does not determine whether a firm will provide better returns or less risk. Financial users need scenarios not just to size the current risk but to also help them understand the ability of a firm to adapt its operations, or to go further and make the necessary investments to reduce carbon intensity. Understanding a corporate's strategy towards large, irreversible investment decisions will help differentiate across firms, but an IAM scenario is unable to provide this level of details.

Financial institutions could develop specific sectoral scenarios that model the impact firm specific constraints and investment barriers and/or may choose to gain a deeper understanding of corporate strategy through engagement with their customers. An IAM does not provide sufficient information to enable a full characterisation of the dynamic risk-reward profile of corporates from the scenario alone.

Box 3 demonstrates the need to understand established economic structures and their potential for change in a transition. It uses as an example, the relationship between the sovereign of Mexico and the State Owned Oil Company (SOOC), and highlights the importance of modelling financial inter-relationships and feedback loops between sectors. As the analysis illustrates, the creditworthiness of the SOOC may be supported by the link to the sovereign, but if a transition causes the financial standing of the SOOC to further deteriorate, financial risk may transmit to the sovereign itself and in turn may alter the level of support the sovereign is able and willing to offer. A user wishing to evaluate the sovereign would need a scenario to present sufficient insight into a sovereign's fiscal position, its potential policy response to transition shocks and potentially, detail on the sovereign's intentions towards the SOOC.

Transition risk will be reflected in asset prices and risk-perceptions of financial market participants. IAM scenarios are silent on financial market behaviour and the unprecedented nature of transition leaves the user with little to draw from in gauging the likely shift in asset prices and risk-premia. What we do know, as Box 4 shows, suggests the reset in financial market expectations could be both significant and swift. Financial markets are unlikely to move in lockstep with the smooth phasing of technology and depending on the scenario narrative, re-pricing can be large and jerky with potential for spillovers to other sectors and asset classes. The implications of transition for the financial system, the feedback to the real economy and the resulting ability of the financial system to support transition are understudied areas.

## Box 3: Sovereign risk

IAMs do not model the sovereign sector and financial firms will need to make additional assumptions to infer fiscal behaviour and potential liabilities of the sovereign in a transition. This additional analysis is needed to calibrate scenario-consistent sovereign risk premia and assess the credit quality of sovereign and sovereign-backed debt. It may not seem obvious that the financial health of the sovereign is relevant in a transition scenario, but implementing climate policy will have fiscal implications arising from factors such as: emissions taxation schemes; sovereign and public sector financing of low emissions technologies; and, even the potential crystallisation of sovereign contingent liabilities (either implicit or explicit) as a result of the reduced dependence on fossil fuels. We use this last example to highlight a gap in IAM scenarios and point to an area where financial users need to make their own assumptions, build out a narrative and provide separate quantification.

Figure 7 shows oil demand across NGFS scenarios: *CurPol* scenarios without additional climate policies ("Hot House World") and in the two transition scenarios consistent with keeping temperature rise to well below 2C by end of the century, namely an orderly transition starting in 2020 (Imm) and a disorderly transition starting in 2030 (dly). The figure shows that although oil remains in the mix throughout the century in most transition scenarios, demand peaks in the 2020s and declines thereafter. In a future of flat or declining oil demand, producers will fight for market share and a shakeout of the market is bound to happen with the most resilient producers surviving through the next decades. A well-managed company with low production costs and high investment capacity is more likely to be successful at navigating the transition than a highly leveraged, poorly managed one.

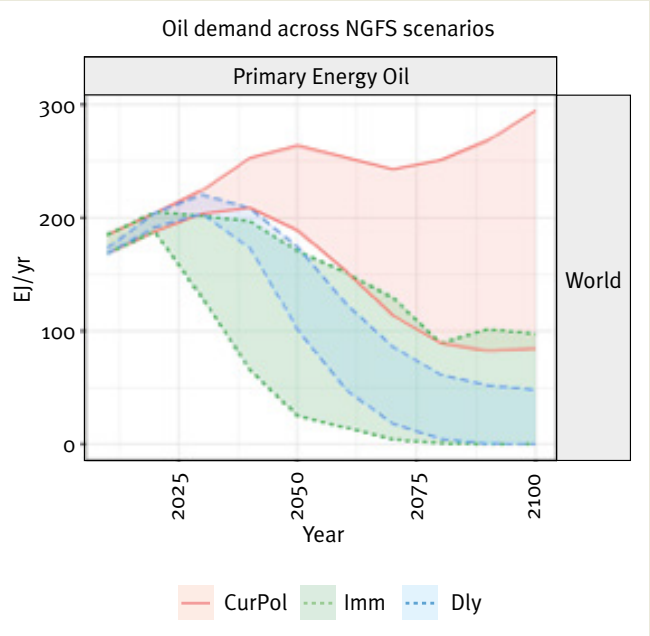



*Figure 7: Oil demand across NGFS scenarios. Ref = Hot House World, a scenario following current trends; Imm = scenarios of immediate (orderly) climate action starting in 2020; Dly = scenarios of delayed (disorderly) climate action starting in 2030. Source: own elaboration based on data from NGFS scenarios database*

Nationally Owned Oil Companies (NOOCs) require special consideration in transition as the extent of sovereign support, either implicit or explicit, tends to be high, and national considerations, including the importance of oil in fiscal revenues, employment in the sector, and the political importance of oil may affect the financial health of the NOOC. Both the willingness and ability of the sovereign to support a NOOC in transition matters, and the way in which the support is offered, can in turn feedback onto the sovereign through an impact on oil revenues, the debt position, and interest commitments of the sovereign. Given the importance of the sovereign in determining the general perception of risk towards a country (particularly in emerging markets), it is possible in certain scenarios that investor risk perceptions towards a country could be affected by a change in the sovereign's financial health.

For a sovereign, transition scenarios need to consider the two-way transmission of risk. Firstly, scenarios need to explain the willingness and ability of the sovereign to support a NOOC facing lower oil demand and higher operating costs, thereby allowing a complete consideration of the financial health of the NOOC at the sector level. Secondly, the scenario should consider the feedback on to the sovereign's own financial health as a result of the support offered. Scenarios that wish to consider realistic outcomes for the sovereign will need to consider the ability of the sovereign to take additional measures to mitigate risk, such as fiscal reform to reduce dependence on oil revenues. This area requires its own narrative and quantification based on consideration of policy options. Figure 8 highlights the inter-relationship between the sovereign and the NOOC as a result of a transition.

We end this section with a brief example using the case of Mexico and its state-owned oil company, Pemex. We do not make the claim that either Mexico or Pemex are vulnerable to a transition as each transition scenario needs to be considered on its own and the assumptions made by the scenario developer will determine outcomes. We choose this example as Pemex is a NOOC currently in financial distress on a stand-alone basis and it is in receipt of sovereign support and this illustrates some of the channels of transmission discussed above.

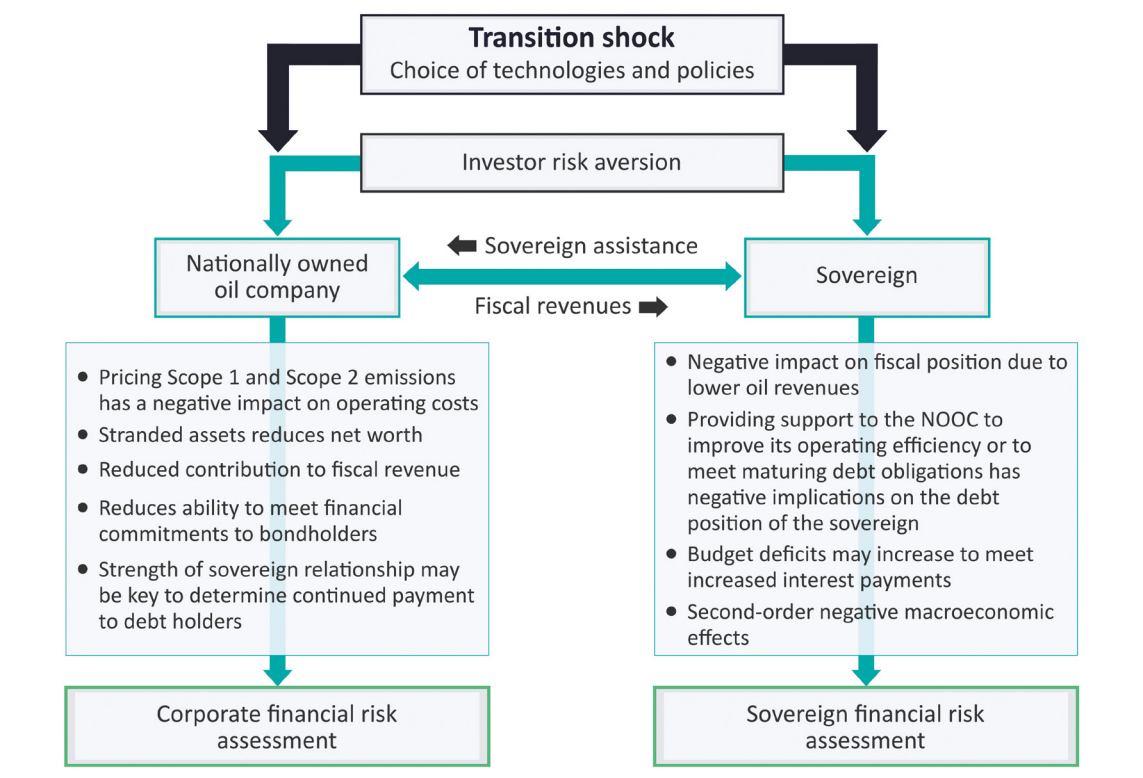



*Figure 8: Transition and the sovereign-corporate feedback loop*

Mexico is the 11th largest oil producer in the world while its proven reserves put it in 19th position[1]. Pemex, the national oil company, responsible for all oil production in Mexico faces transition risk in any mitigation scenario as a result of decreasing global dependence on oil. Pemex's stand-alone financial position has been weak for a number of years and rating agencies have noted that its standalone credit profile reveals deep vulnerabilities. The rating agency Fitch noted after a recent credit downgrade of both the company and the sovereign that *'Pemex's standalone deterioration reflects the company's limited flexibility to navigate the downturn in the oil and gas industry given its elevated tax burden, high leverage, risking per-barrel lifting costs and high investment needs…'*[2].

Pemex performs poorly on a number of financial metrics and its ability to service its debt and its continued access to debt markets depend on the support it enjoys from the sovereign. With more than $110bn of debt, its ability to manage its debt burden in transition will be of significant interest to debt holders. Its existing vulnerabilities – continued net losses from operations, steady decline in capital expenditures, negative free cashflows, and high degree of leverage – suggest that without sovereign support, meeting interest commitments and continued access to debt markets may be a significant burden for Pemex in certain transition scenarios. The existing relationship under which the corporate enjoys implicit state support – a fact clearly recognised by rating agencies when setting Pemex's credit ratings – needs to be re-evaluated in a scenario. While the Mexican government does not explicitly guarantee Pemex, it is the close ties with the sovereign that have enabled the oil company to avoid default recently[3]. The sovereign clearly plays an important role in managing Pemex and in turn relies on oil revenues.

Conversely, Pemex's large outstanding debt and the possibility that these end up being supported by the sovereign, and hence add to the sovereign own debt commitments, may drive further investigation of second-order effects on the Mexican sovereign and the wider economy. Similar to a number of other oil-producing nations, the fiscal position of the Mexican government depends on oil revenues. The sovereign's ability to undertake fiscal reform, broaden its tax base, decrease its reliance on oil revenues[4] and manage any increase in its deficit position – as a result of having to assume the debt of the NOOC – will impact the sovereign's own credit standing.

1 BP Statistical Review of Energy, 2019.
2 Fitch, April 2020. Rating Action Commentary. 'Fitch downgrades PEMEX, CFE, IEnova and Cometa after Sovereign downgrade.'
3 The 2020 government budget plan included $4.4bn contribution to Pemex, including cash and tax relief, in addition to which the government also announced a further cash injection of $5bn in 2019 Sep. Pemex commented that it would use the cash injection to pay down debt holders. Financial Times.
4 Fiscal reform possibilities for Mexico highlighted in IMF in its 2019 Article IV consultation include *'rationalising regressive tax expenditures, broadening the tax base, lowering the threshold for the top PIT bracket, abolishing border incentives and fuel price support'* amongst others.

## Box 4: Coal

IAMs project a complete phase out of coal-fired power generation without carbon capture and storage (CCS). The timing and speed of this phase out depends on the stringency of near-term climate policy, with important implications for the stranding of coal assets[46], the market valuations and default of coal mining companies and downstream users. In an IAM scenario, the complete phase-out of coal takes a number of years to achieve and is driven by assumptions made about the price of emissions.

In selecting a scenario for coal, financial users should pay attention to the assumptions made when translating global commitments to individual countries and possibly even geographically within a country. An individual country's stance towards coal will be important to consider in valuing coal investments – some countries may choose to phase out coal altogether, while in other countries, the cost of phase out may be too high and coal may continue to survive, even counting the added cost of CCS. Social and political constraints, like employment and potentially negative sectoral spill-overs, may also hinder a full coal phase out in some places.

Coal has felt the effect of public policies of various types. In the US the combination of Obama era power plant policies, with the rise of cheap shale gas has cascaded to the coal mining sector. In India, the introduction of air pollution standards may force the closure of old, inefficient power plants, many of which are already operating under a substantial debt burden. Buoyed by the steep fall in the cost of renewables including wind and solar PV, the Indian government has also announced aggressive renewable energy targets for 2022 and 2030. The recent announcement by the world's largest consumer of coal, China, to achieve net zero by 2060 will have a further impact. In addition to existing climate and air and water pollution policies, the changing economics of renewable energy will also ensure that the downward trend in coal production continues.

Such considerations may feedback either into scenario design and be used to select an appropriate IAM scenario or may create a requirement to create heterogeneity at the country level for coal production and usage for a given global or regional pathway during the scenario expansion process.

Scenario design should also consider the ability of an IAM to successfully capture real-world price dynamics, particularly, the potential change in risk premia that financial markets are likely to require to finance coal producers and users in a scenario where coal is completely phased out, and in the timing of such a reset in expectations. IAMs pathways are constructed around demand and cost conditions and do not capture financial market expectations. Figure 9 shows the price path for coal from the various NGFS scenarios.

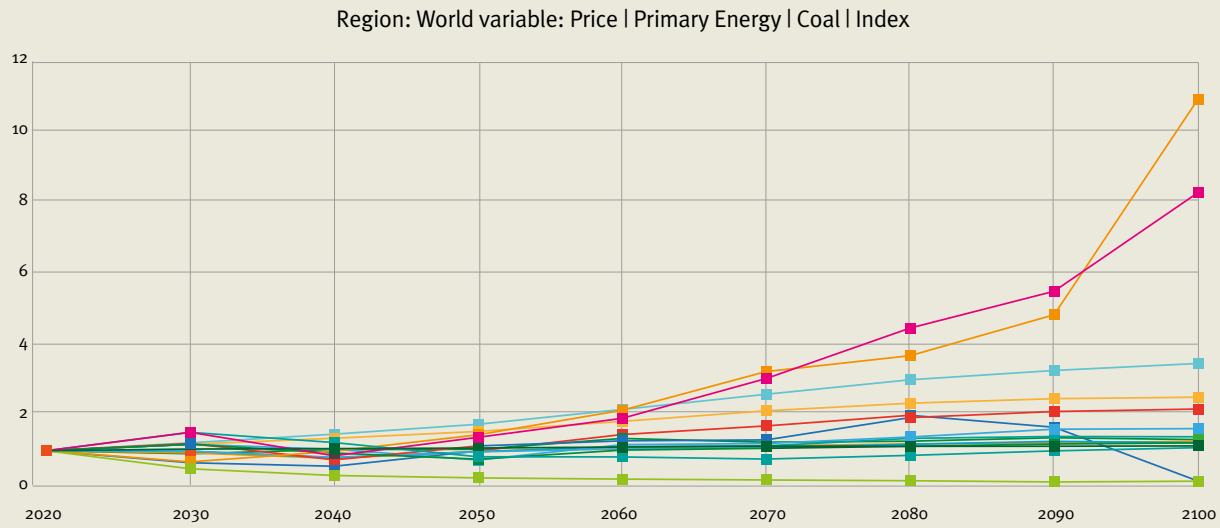



*Figure 9: Coal price (index) across NGFS scenarios*

As the figure shows, prices follow a smooth path, calibrated at long intervals of 5-year steps with a scenario horizon out to 2100. Using an IAM scenario pathway for coal to assess financial risk for the sector is likely to proceed by building a link between scenario variables such as the carbon price and coal volume and price assumptions and underlying firm level profits, investments and valuations.

Such an approach will produce a risk profile that deteriorates in line with the increase in the carbon price and the reduction in the global demand for coal. But this will not capture the impact of short-term, rapid, changes in financial market expectations on valuations and default. It is generally acknowledged that financial markets adjust rapidly and are likely to reprice assets in anticipation of policy rather than follow the smooth adjustment path produced by an IAM scenario that models underlying cost and demand. Such real-world re-pricing may contribute significantly to price volatility and lead to a very different view of valuations and default conditions compared to those implied by a smooth phase-out scenario. The challenge for the financial user is to convert the path of coal in an IAM scenario into an appropriate risk price.

History can provide some insights into the potential speed of price adjustment and the potential for default in this industry. The US coal industry experienced several years of significant change between 2010 and 2019. Difficult mining geology in some basins, the fall in the share of coal for electricity generation in the US (because of an increase in the share of gas and renewables), Obama era clean-policy reforms and slowing international demand affected coal companies in the US. Figure 10 shows the historical price of coal from 2009-2019 and the occurrence of coal company defaults during this period. The sharp fall in the price of coal during the period 2010-2015 reflects a number of factors and cannot be linked purely to climate policy, but compared to the smooth trend paths in Figure 1, it shows that short-term price volatility can be considerable and is correlated to episodes of default. As the global demand for coal increased during much of this period[47], it also shows that price evolution can incorporate factors other than underlying demand.

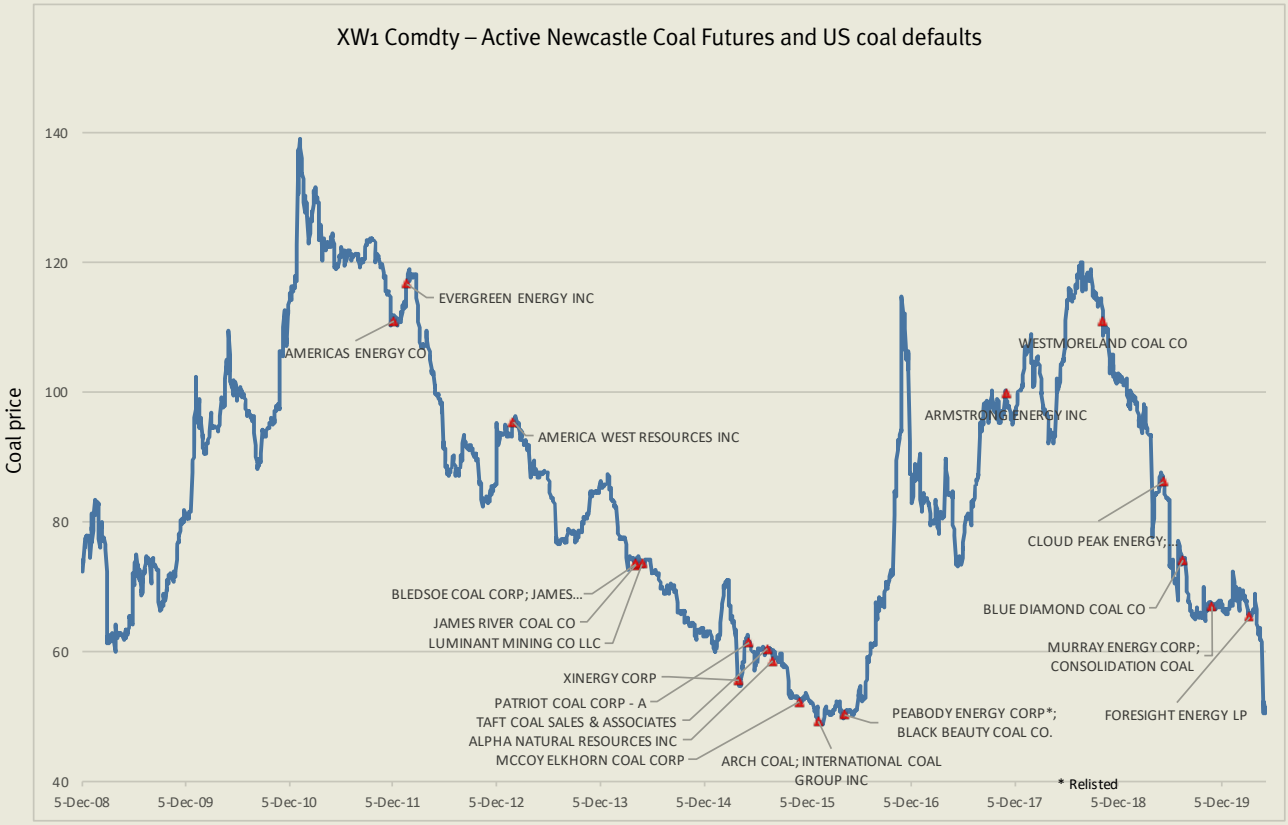



*Figure 10: Evolution of coal prices and US coal companies' bankruptcies (red dots)*

In closing, heterogeneity at the county level naturally extends to the individual corporate producer and user of coal. Box 2 has illustrated some of the challenges in translating IAM scenarios into firm-level impact for the EU utilities sector and the coal sector also presents challenges when translating global policy into firm-level impact. A decline in coal production does not imply the immediate demise of every company in the sector across every country. Not only is it important to identify the pockets of demand that could exist as outlined above, company-specific factors, such as operating costs and financial leverage, will influence market valuations and default conditions. Such considerations are beyond the ability of a top-down scenario to consider and results from a top-down scenario need to be assessed alongside a bottom-up portfolio review.

Finally, while Cormack et al (2020) and Allen et al (2020) present users with methods to expand scenarios, these studies benefit from their focus on advanced economies given the availability of richer data and more granular models. Extending scenarios to emerging markets will present additional data and modelling challenges, requiring financial users to use additional judgement.

Financial firms will need to carefully consider the extent of expansion required and the most appropriate tools to deploy. There is no easy plug-and-play solution, at least not yet and not for the foreseeable future. The vetting of any tools is already part of the governance of risk assessment frameworks within the financial sector. For climate risks, due diligence requires understanding model risk and uncertainty to ensure insights are robust. There is no "better model" or "more appropriate scenario". Rather, each of them has strengths and weaknesses and have more or less defensible representations of a specific sector, region or technology. Understanding how to contrast and compare models and scenarios, their assumptions and structures, and how all these drive the results can help determine the confidence in the insights derived from the applied frameworks.

## 4 Embedding climate scenarios

Accounting for the multiple transmission channels of climate related risks in a dynamic framework that reflects the structural changes brought by a transition and how economic agents react is a task filled with uncertainty. It probably means that solving the methodological challenges may not suffice to allow extracting numerical results robust enough to guide strategic positioning and setting risk appetite. Still, in spite of these caveats, scenario-based analysis is a powerful tool to improve a firm's chances of adapting to future risks[37].

Scenarios need to be tailored to provide insights into the financial performance of portfolios and should be clear in setting boundaries for analysis. Each user needs to extract relevant information from existing or bespoke scenarios to inform their decision making in a way that is adjusted to their specific needs. The needs of a large global universal bank are likely to differ from those of a regional retail lending institution. In addition, there is a trade-off between usefulness and complexity, particularly relevant as financial firms build out their climate scenario capabilities, which will limit the features of transition and physical risk that users seek to focus on. Firms face the daunting task of gathering climate related data on their counterparties and building financial models with embedded climate factors and the current maturity of models and data will motivate the complexity underlying scenarios – there will be diminishing returns to added scenario complexity.

While the specifics of scenarios depend on the profile of the user, climate financial scenario analysis should be directed towards both risk management and strategic planning by all firms. For **risk management** purposes, scenarios can help evaluate the impact of transition on valuations of assets and collateral and the default risk of loans to calibrate risk appetite and explore the actions necessary to manage risk and alter the risk profile of the institution. For **business planning**, firms can use climate scenarios to both identify appropriate climate strategies and also to measure the achievability of plans to build sustainable businesses. This means using scenarios to deepen understanding of the enablers and impediments of transition and the risk and reward characteristics associated with the investment required in support. Finally while risk management scenarios are primarily directed towards improving an understanding of financial risk i.e. the risk of loss on loans or loss in value of assets, climate scenarios could also be considered to improve understanding non-financial risks, such as the legal and reputational risk that arises from not aligning portfolios to climate goals.

Financial institutions should use a variety of scenarios to help them work their way through the uncertainty surrounding climate transition. Financial firms will need multiple scenarios to help them separate the mix of global and national ambition, chosen policies and technological possibilities as discussed in Section 3. Firms need to identify a transition scenario that they consider to be the 'most-likely' and should use this to build out a baseline or planning scenario. Firms should examine alternative paradigms around this baseline and in doing so should pick assumptions that are suitably differentiated, and that lead to distinct financial outcomes, both positive and negative. The NGFS provides the most up-to-date suite of financial scenarios and can be a useful starting point.

A significant amount of transition risk will arise in the near term as governments and corporates set new targets determined both by science and political motivations, but IAM scenarios are silent on near term effects. There is a need to link the long term with the near-term, to create scenarios that consistently draw out the immediate financial implications of decisions that affect global temperatures over a much longer horizon. Building out short term transition scenarios based on declared intentions and real world economic and financial changes will be the next challenge.

Finally, climate change will invariably lead to financial consequences. In the absence of mitigation, the impacts from temperature rise will lead to changes in the productivity of labour and capital and increase the demand for investments into adaptation. Tipping points in the geo-system can trigger unpredictable socio-economic dynamics and may lead to significantly larger economic loss than current estimates show [need ref]. Abrupt and extensive mitigation could have negative systemic financial consequences because of a large scale re-pricing of risk. Well implemented, carefully planned policy will, not only, provide financial opportunity but may also spark a virtuous cycle of investment and growth. In all these cases, scenario analysis can be used to provide useful insights – but using a single approach with the same set of tools to answer all questions is unlikely to provide rich enough analysis.

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