7

Climate Models and Scenario Analysis

Learning Objectives

After completing this reading you should be able to:

- Define scenario analysis and climate scenario analysis.
- Describe how climate scenario analysis is used by organizations.
- Describe IPCC scenarios and associated representative concentration pathways (RCPs) and shared socioeconomic pathways (SSPs).
- Understand the difference between RCPs and SSPs.
- Describe IEA scenarios and other global reference scenarios.
- Identify scenario parameters, corresponding outputs, and their business application.
- Explain how scenario analysis is used for assessing transition risk.
- Explain how scenario analysis is used for assessing physical risk.
- Describe how corporations use scenario analysis to set corporate strategies and communicate with stakeholders.

- Examine how corporations conduct scenario analysis for mitigation of operational risk and resiliency planning.
- Describe how financial firms use climate scenario analysis.
- Explain different aspects of climate scenario analysis using case studies.

This chapter describes how climate change risk can be modeled and analyzed through the use of scenarios, which can help companies and financial institutions to prepare for various possible physical and transition climate-related outcomes. The chapter begins with an introduction to scenario analysis as a general planning tool for companies. The chapter then reviews commonly used reference scenarios used by climate scientists, policymakers, and corporations. Then the chapter examines climate scenario analysis as applied to physical and transition risk, building on the material in Chapter 3. The chapter ends with a detailed look at use cases of scenario analysis both in corporations and in a financial context.

Chapter Outline

Key Learning Points

- **Scenario analysis** refers to the use of narratives to sketch out potential future states of the world. While it originated in academic research in the 1950s, it was soon applied by some large corporations, and it is now widely used to analyze climate risk.
- **Global reference scenarios** are agreed and widely used projections of future emissions, sometimes with socio-economic narratives attached, which are a crucial input for climate scenario analysis.
- The most universal reference scenarios are from the **IPCC,** including **representative concentration pathways (RCPs)** and accompanying **shared socioeconomic platforms (SSPs)** that allow for more societal and economic nuance, as well as policy changes, to be incorporated into RCPs.
- Other important providers of reference scenarios are the **International Energy Agency (IEA),** Greenpeace, IRENA, and the NGFS.
- Scenario analysis, while often starting with these reference scenarios, requires a number of decisions to be taken. Firstly, various **parameters/assumptions** must be set, **analytical tools** chosen, and **outputs.**
- Transition risk scenario analysis can make use of **integrated assessment models (IAMs),** economic models that also include representations of societal and environmental phenomena and **sector-specific decarbonization pathways.**
- Physical risk scenario analysis uses **physical climate models,** but it also benefits from resilience planning. The physical impacts of climate change will be relatively similar between now and 2050 under any plausible emissions trajectory, which is why short-term scenario planning is more about preparedness than variation between trajectories.
- Corporations, financial and non-financial, use scenario analysis for **strategy and stakeholder communication** to investors and regulators. Scenario analysis is also used for **resilience planning.**

- Financial firms, in addition, use scenario analysis for **portfolio risk management and stress testing** as well as pre-emptively in **portfolio selection.**

CLIMATE MODELS AND SCENARIO ANALYSIS

7.1 Introduction to Scenario Analysis

This chapter examines how climate models and scenario analysis can be a useful tool for both non-financial corporations and financial institutions to respond to the challenges of climate change, including risks related to both physical impacts of climate change (physical risks) and the zero-carbon economic transition (transition risks).

Scenarios, as well as models (for which scenarios are used as inputs), are critical tools for climate risk management. Scenario analysis is flexible enough to draw together nearly all the relevant issues, risks, and their interrelationships in one approach, and it can yield results applicable for many purposes, ranging from reporting to shareholders or stakeholders and setting internal company strategy to making investment decisions.

Scenario analysis, in its broadest sense, is the practice of planning through describing and sketching the future using plausible narrative stories ("scenarios"). The concept originated in academic research in the 1950s and is often credited to Herman Kahn, an American researcher, though similar concepts were developed around the same time in France. Scenario analysis spread quickly beyond academic circles to corporations, such as General Electric, DHL, and Royal Dutch Shell, the Anglo-Dutch oil & gas firm.

Indeed, corporations in general, and Shell in particular, played an outsize role in developing and maturing the technique. Shell's "futures" team, which took shape in the 1960s, sent its first oil-price forecasts to executives in the early 1970s. The founders of the team shied away from attempting to assign probabilities, but they prioritized plausible scenarios, even ones that seemed improbable. The approach quickly proved its value to the firm by helping it to be prepared for the kind of scenario that played out in the oil crisis of 1973. The point of the team, however, was not to predict the future accurately; its value was in ensuring a firm-wide approach to preparedness, which has continued ever since (Wilkinson, 2013). This sort of scenario planning has, in more recent decades, been applied to a wide variety of challenges, such as ensuring that the end of apartheid occurred peacefully in South Africa, PepsiCo's changes in demand in response to changing consumer food and beverage preferences, and climate change.

In recent years, **climate scenario analysis**, that is, the use of climate scenarios for analysis and decision-making, has become a preferred tool of both non-financial corporations and financial institutions. Climate scenario analysis is used to bolster corporate preparedness in the face of physical and transition-related climate impacts to communicate that preparedness to investors and other stakeholders and to guide strategy and investment decisions at all types of firms. It is also starting to be integrated into asset allocation and investment decisions at some financial firms.

The recommendations of the Taskforce on Climate-Related Financial Disclosures (TCFD) are an important starting point for understanding the role of scenario analysis. The TCFD recommends scenario analysis as a way to "enhance critical strategic thinking" and challenge conventional wisdom regarding the future using plausible, distinctive, consistent, relevant, and challenging scenarios (see box). The TCFD essentially recommends flexible, corporate-specific, forward-looking analysis that is not dissimilar to the approach pioneered at Shell in the 1960s.

However, this type of high-level, strategic scenario analysis is not the only use of the approach when it comes to climate. Indeed, while each organization and firm does face a different blend of climate-related risks and opportunities, and it can make sense to customize scenarios for firm-specific use, analysis of climate change is often done using a set of standard, cross-comparable scenarios. These **reference scenarios** are a set of agreed-upon projections of global emissions trajectories, with accompanying socio-economic narratives and estimates for physical impacts

TCFD RECOMMENDATIONS ON SCENARIO ANALYSIS—EXCERPTS

"What is a Scenario Analysis?

- Scenario analysis is a tool to enhance critical strategic thinking.
- A key feature of scenarios is that scenarios should challenge conventional wisdom about the future.
- In a world of uncertainty, scenarios are intended to explore alternatives that may significantly alter the basis for "business-as-usual" assumptions.

Scenario Characteristics

Plausible: The events in the scenario should be possible and the narrative credible (i.e., the descriptions [...] should be believable).

Distinctive: Each scenario should focus on a different combination of the key factors. Scenarios should be clearly differentiated in structure and in message. [...]

Consistent: Each scenario should have strong internal logic. The goal of scenario analysis is to explore the way that factors interact [...]

Relevant: Each scenario, and the set of scenarios taken as a whole, should contribute specific insights into the future that relate to strategic and/or financial implications of climate-related risks and opportunities.

Challenging: Scenarios should challenge conventional wisdom and simplistic assumptions about the future [...] [and] business-as-usual assumptions.

Source: TCFD.

(as calculated by climate models). Sometimes, these scenarios include sector-specific pathways. The most widely used, and widely agreed upon, reference scenarios are those created directly by the Intergovernmental Panel on Climate Change (IPCC), although scenarios from the International Energy Agency, an international organization, and from various non-profit and academic sources are also widely used. The use of such common reference scenarios allows for cross-comparability, both across firm types and across different use cases. Furthermore, combinations of scenarios are often used in tandem to help cover gaps in coverage for a particular time frame, sector, or regional geography of interest.

Scenario analysis for climate change varies quite significantly between the two main types of climate risk, namely transition and physical risk (Section 7.3). For transition risk, non-financial corporations or financial institutions typically examine whether their facilities, strategies, and portfolios align with one of the global projected emissions trajectories. Or else, they examine the potential effects of climate policy tightening (e.g., a higher carbon tax) on their operations and plans. For physical risk, emissions trajectories, when "plugged in" to a physical climate model, allow for producing estimates of temperature rise, precipitation, weather extremes, and other phenomena. But, due to the lag in the global climate system, the physical outcomes of climate change are practically the same for the next few decades (until about 2050) regardless of emissions. Therefore, to improve firms' preparedness and resilience, for physical risk specifically, scenario analysis is more about using the sorts of physical climate impacts that are already occurring and expected to continue. For physical risk, emissions trajectories only make a difference on very long timescales, whereas for transition risk, emissions trajectories make a very significant difference even on short timescales. There is an enormous difference for companies or financial institutions between continued flat or rising emissions ("business as usual") as compared to hitting goals such as net-zero emissions by 2050, which requires drastic cuts by 2030.

Finally, the use cases of scenario analysis are varied and ever broadening. Besides its use in high-level strategy setting and corporate disclosure, as recommended by the TCFD, scenario analysis is being integrated in concrete ways by non-financial firms and financial ones alike. For non-financial firms, climate scenario analysis can allow for concrete preparedness actions to be taken with regard to specific facilities (offices, factories, etc.), and it can be used for capital expenditure investment decisions. For financial firms, climate scenario analysis can be useful to gauge portfolio alignment with goals such as the 2°C goal of the Paris agreement, to pre-empt or shape new investment decisions by portfolio managers, or to provide a top-down "stress test" approach where a portfolio is tested under certain assumptions and conditions.

From being simply a "nice to have" tool or one recommended as best practice, scenario analysis is increasingly being implemented by, and even mandated by, regulators. Stress tests, which model the reaction of both a financial system as a whole and an individual institutions' balance sheets to a hypothetical shock, rely on scenario analysis by their very premise (see also Chapter 5). Stress tests were widely adopted by regulators in the wake of the global financial crisis of 2008 and are now increasingly being repurposed to examine climate change risk. The Bank of England (BoE), the Banque de France, and the Nederlandsche Bank (the Dutch central bank), as well as the European Central Bank are at various stages of implementing climate stress tests with differing degrees of granularity, distinct climate and policy scenarios, time horizons, and feedback loops. Starting in 2021, the BoE's first climate stress test, called the Climate Biennial Exploratory Scenario, is set to be run biannually. The US administration under President Joe Biden has also mandated America's financial regulators, as of May 2021, to develop a comprehensive approach to assessing financial-sector climate risk, which may include scenario analysis.

7.2 Global Reference Scenarios

This section discusses global-level climate reference scenarios, which are key inputs for corporate and financial scenario analysis. The most widely agreed upon, and the most widely used, come from the Intergovernmental Panel on Climate Change (IPCC), with those from the International Energy Agency and a few other key organizations also in common use.

7.2.1 IPCC Scenarios (RCPs and SSPs)

The concentration of greenhouse gases in the atmosphere is key to the Earth's climate, yet the concentration is being swiftly altered by human activity. Because of this fact, modeling and predicting the future trajectories of the greenhouse gases in the atmosphere is arguably the single most important factor to understand—more so than having the physical parameters of a climate simulation model exactly correct. Indeed, given accurate emissions trajectory data, even simple climate models can perform quite well in predicting global warming. (See Section 7.3 for more information on models.)

Because of this, there has understandably long been a focus among climate scientists in the IPCC to, if not definitively predict the single future path of emissions, at least lay out plausible, agreed-upon scenarios. These climate scenarios would then provide a common starting point for modelers. The first iteration of such scenarios was devised in the 1990s, with assumptions about population growth, economic growth, and emissions. From these beginnings among scientists, these kinds of scenarios have now become a crucial reference point for policymakers, corporate managers, and investors alike.

Current IPCC usage and modeling is based on **representative concentration pathways (RCPs)**, which are agreed-upon, projected, plausible emissions pathways through 2100. These pathways represent different emissions projections under basic, plausible economic and social assumptions, while staying within physical constraints.

The RCPs were constructed by back-calculating the amount of emissions that would result in a given amount of radiative forcing—the difference between solar radiation (energy) absorbed by the Earth and energy radiated back into space (as covered in Chapter 1)—that would then result in a given amount of warming. Because of this, the RCP names are based on the amount of radiative forcing measured in watts/meter squared (m^2), and they do not correspond neatly with the anticipated amount of warming in degrees Celsius.

Note that because different physical climate models yield somewhat varying predictions based on the same emissions trajectory, the amount of warming corresponding to any given RCP is only approximate, not absolute. For RCP 2.6, the pathway often used as shorthand for "below 2°C," 22% of CMIP5 models (the ensemble of models used for the 2014 IPCC report) found that global temperatures in fact surpassed that threshold, meaning that there is only a 78% probability that global temperature does remain below 2°C (Collins et al., 2013).

The table below lists the RCPs; the corresponding approximate, global average temperature rise by 2100; and the shorthand, if used. The most widely used models tend to be RCP 2.6 and RCP 8.5. RCP 2.6 is used as a shorthand

Table 1

PRE-2021 RCPS

Pathway Name	Corresponding Rise in Global Average Temperature by 2100	Emissions Trend to 2100	Approximate Equivalent/ Shorthand
RCP 1.9	~1.5°C	very strongly declining	
RCP 2.6	~2.0°C	strongly declining	"Paris aligned"
RCP 4.5	~2.4°C	slowly declining	
RCP 6.0	~2.8°C	stabilizing	"current policies"
RCP 8.5	~4.3°C	rising	"business as usual"

for reaching Paris goals (of limiting warming to below 2°C) by drastically cutting emissions. RCP 8.5, sometimes called "business as usual," and sometimes, confusingly enough, used as a "worst-case scenario," is a scenario that assumes continued rising emissions, leading to much higher levels of warming. RCPs, while originating with the IPCC, can now be found in everything from financial regulatory reports to commercially available climate risk tools meant for corporations. The RCPs that were current at the time of writing are being updated to include socioeconomic factors more explicitly.

For analytical clarity, the RCPs did not originally include a socioeconomic "narrative" but only emissions trajectories calculated using certain assumptions about energy use. Instead, **shared socioeconomic pathways (SSPs)** (as covered in Chapter 1) have been developed subsequently to be used in conjunction with the RCPs. SSPs are intended to provide plausible scenarios for how the world evolves in areas such as population, economic growth, education, level of globalization, level of urbanization, and the rate of technological development.

The five SSP scenarios range from better to worse climate change outcomes. SSP-1 sketches out a scenario of significant focus on sustainability; SSP-2 is a "business as usual" scenario; SSP-3 involves regional rivalry between countries; SSP-4 has a high degree of inequality; and SSP-5 posits fossil-fuel development.

The SSP base scenarios deliberately do not include climate policies. The reasoning is that the SSPs can be combined with different RCPs to explore the climate policy options and assumptions that are necessary to limit global warming to a particular target level. Specifically, shared climate policy assumptions capture key policy attributes such as the goals, instruments, and obstacles of mitigation and adaptation measures, and they introduce an important additional dimension to the scenario matrix architecture.

For instance, RCP2.6 and RCP1.9 are both possible to achieve under the baseline SSP1 assumptions, but with tighter climate mitigation policies in the latter. RCP2.6 is a plausible emissions pathway under both SSP1 and SSP2, but the underlying socioeconomic drivers and outcomes are different.

Because the SSPs took longer to elaborate than the RCPs, they were not included in the 2014 or 2018 IPCC reports, but they will be included from 2021 onwards. So instead of sketching an emissions pathway that is merely RCP2.6, climate modelers will be using, say, SSP-RCP2.6. When examined purely through the output of emissions pathways, the outputs look fairly similar (see graph), but the SSPs nonetheless add value in significant other ways. For example, SSPs may be useful for transition and liability risk assessment, and for evaluating opportunities. In general, because they allow many different ways to achieve the same (or similar) emissions outcomes, they provide more flexibility for models and scenarios.

Having the SSPs alongside, but separate from, RCPs allows the two to be mixed and matched. This permits the exploration of climate policy options and their impact on energy use, land use, emissions, and economic activity in a matrix-type format. To compare matrix rows is to compare different levels of climate policy stringency (as rows are different RCPs); to compare matrix columns is to compare different baseline socioeconomic situations, but the same level of climate policy stringency (different SSPs) (see graph).

However, not all RCPs are achievable under all SSPs—a high-mitigation scenario is not feasible under the SSP3 "regional rivalry" assumptions. The models that can assess

UPDATED EMISSIONS SCENARIOS—"PLAIN" (PRE-2021) RCPS VS RCP-SSP COMBINATIONS

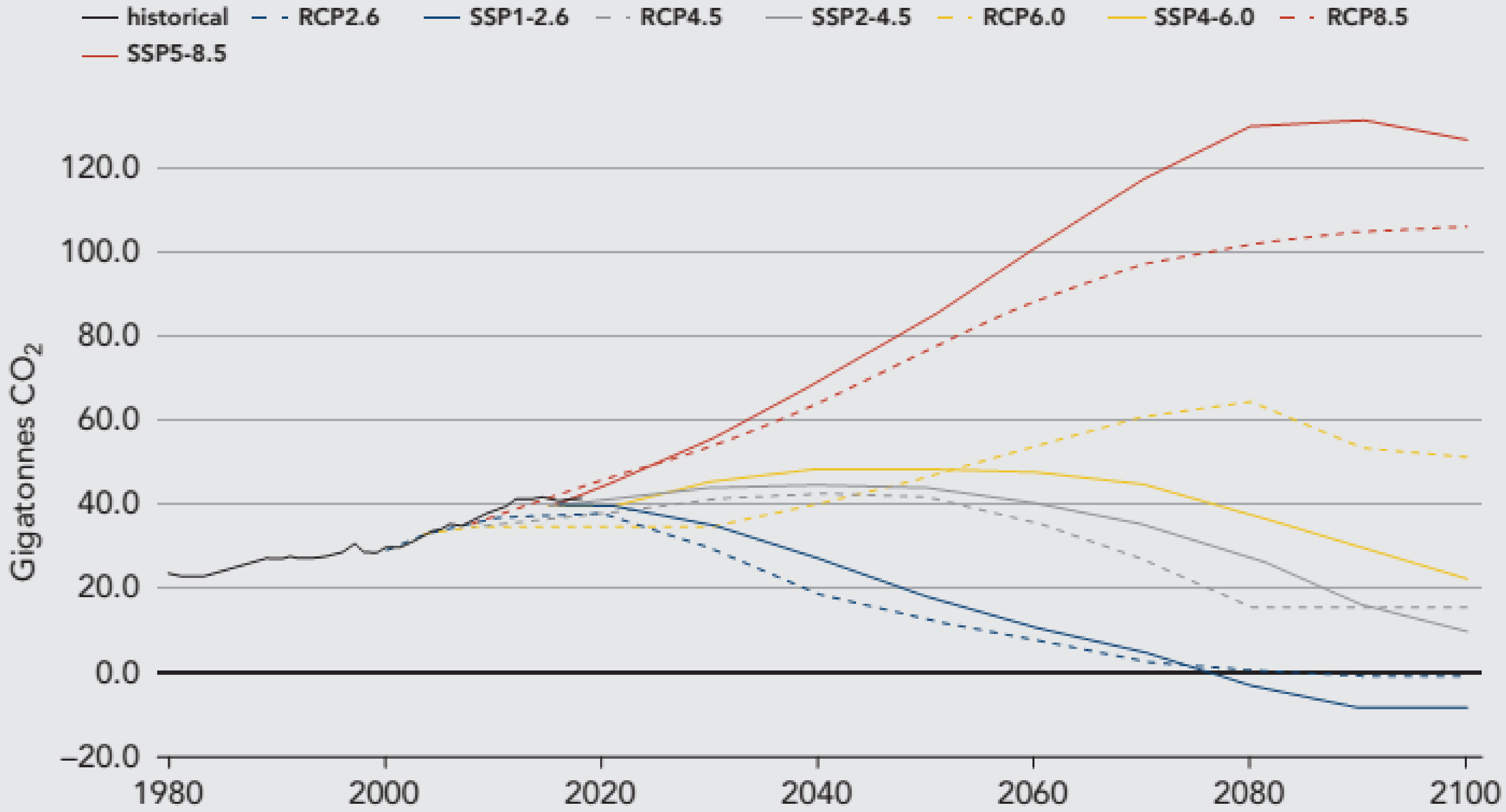

Figure 1

When compared side by side, the pure RCP emissions trajectories previously used by the IPCC (dotted lines) and the combined SSP-RCP trajectories that will be used from 2021 onwards (solid lines) do not look radically different. But there are some notable differences. For instance, the mix of CO_2 and non-CO_2 (e.g., methane) emissions are different even between trajectories that result in the same amount of end-of-century radiative forcing. Also, the old RCPs started in 2007, and the new pathways start in 2014. The 2°C-compliant SSP1-RCP2.6 has a higher starting point than the old RCP2.6, reflecting higher emissions in the 2007–2014 period and a slower initial decline, both of which are made up for by much larger expected negative emissions at the end of the century than in the original scenario. The SSP scenarios are also useful in adding flexibility because they allow for multiple ways to achieve the same (or similar) emissions outcomes.

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the combination of social, economic, energy, emissions, and climate factors are called integrated assessment models.

As important as the IPCC's RCPs and SSPs are as a reference point, the IPCC is not the only organization to have put out scenarios. Several other organizations' projections are also used widely by governments, companies, and financial institutions.

7.2.2 IEA and Other Reference Scenarios

There are a limited number of global, macroeconomic climate scenarios and predicted emissions trajectories from organizations beyond the IPCC that are used widely enough to be considered reference scenarios.

Most important among these are the scenarios developed by the **International Energy Agency** (IEA). The IEA's two core scenarios are the 1) Stated Policies Scenario, which reflects existing policy frameworks and announced policy intentions, and 2) the Sustainable Development Scenario (SDS), which combines climate and social targets and limits warming to 2°C in line with Paris targets.

The IEA has also modeled net-zero emissions by 2050 scenarios. After years of being criticized for consistent underestimation of the potential for renewables and expecting the persistence of fossil fuels, the IEA's report on net-zero of May 2021, its most comprehensive up to that point, laid out a much more ambitious path to the achievement of net-zero (see box). The IEA has occasionally modeled other scenarios as well, such as a delayed economic recovery scenario in 2020 in response to the global COVID-19 pandemic.

MATCHING SSPS AND RCPS SHARED SOCIOECONOMIC PATHWAYS

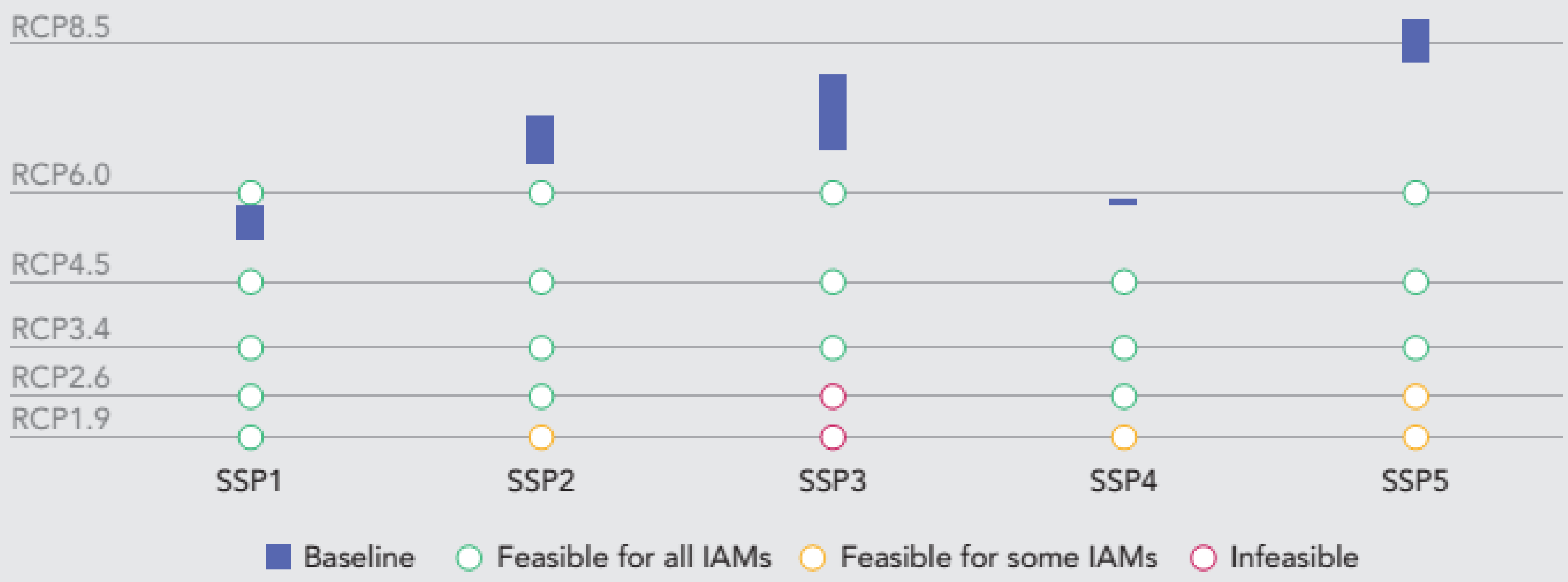

Figure 2

This graphic shows how the baseline SSP assumptions map onto RCP emissions trajectories (blue bars), and it maps which RCPs are achievable under which SSP scenarios, using integrated assessment models.

Reprinted from Senses (2020), Climate Change Scenario Primer with permission of the Potsdam Institute for Climate Impact Research.

IEA: FROM LAGGARD TO THE FOREFRONT

The International Energy Agency's annual benchmark, the ***World Energy Outlook****, is considered one of the definitive global assessments of the energy sector. However, it has been criticized in the past for its perceived excess caution and friendliness toward the fossil-fuel sector.*

For instance, for well over a decade, the IEA forecasts on renewable energy uptake have consistently underestimated their growth. This discrepancy has been the largest and starkest within the amount of solar photovoltaic capacity added annually (see left graph).

In recent years, the IEA has moved towards analysis of deeper decarbonization scenarios that do in fact embed a strong and quick transition. In 2019, after pressure from large institutional investors to include an energy model compatible with 1.5°C goal, the agency did so in its 2020 outlook.

By 2021, the IEA published a detailed report and scenario for achieving global net-zero emissions by 2050 that represented its most ambitious and comprehensive analysis of this target to date. This new ***Net-Zero Scenario*** *left far less room for continued fossil-fuel production and use than previous IEA models had.*

Specifically, the 2021 net-zero scenario sets out a number of sector specific milestones that the IEA argue need to occur to actually reach net-zero by 2050. From 2021, the agency says there should be no new coal power plants, no new coal mines, and no new oil and gas exploration. To be on track, by 2030, the world needs to achieve 60% of vehicle sales being electric, a phaseout of existing coal plants in developed economies, and over 1GW of additional solar and wind capacity needs to be added per year. By 2040, 50% of buildings need to be retrofitted and electricity generation emissions globally need to reach net-zero (see graphic).

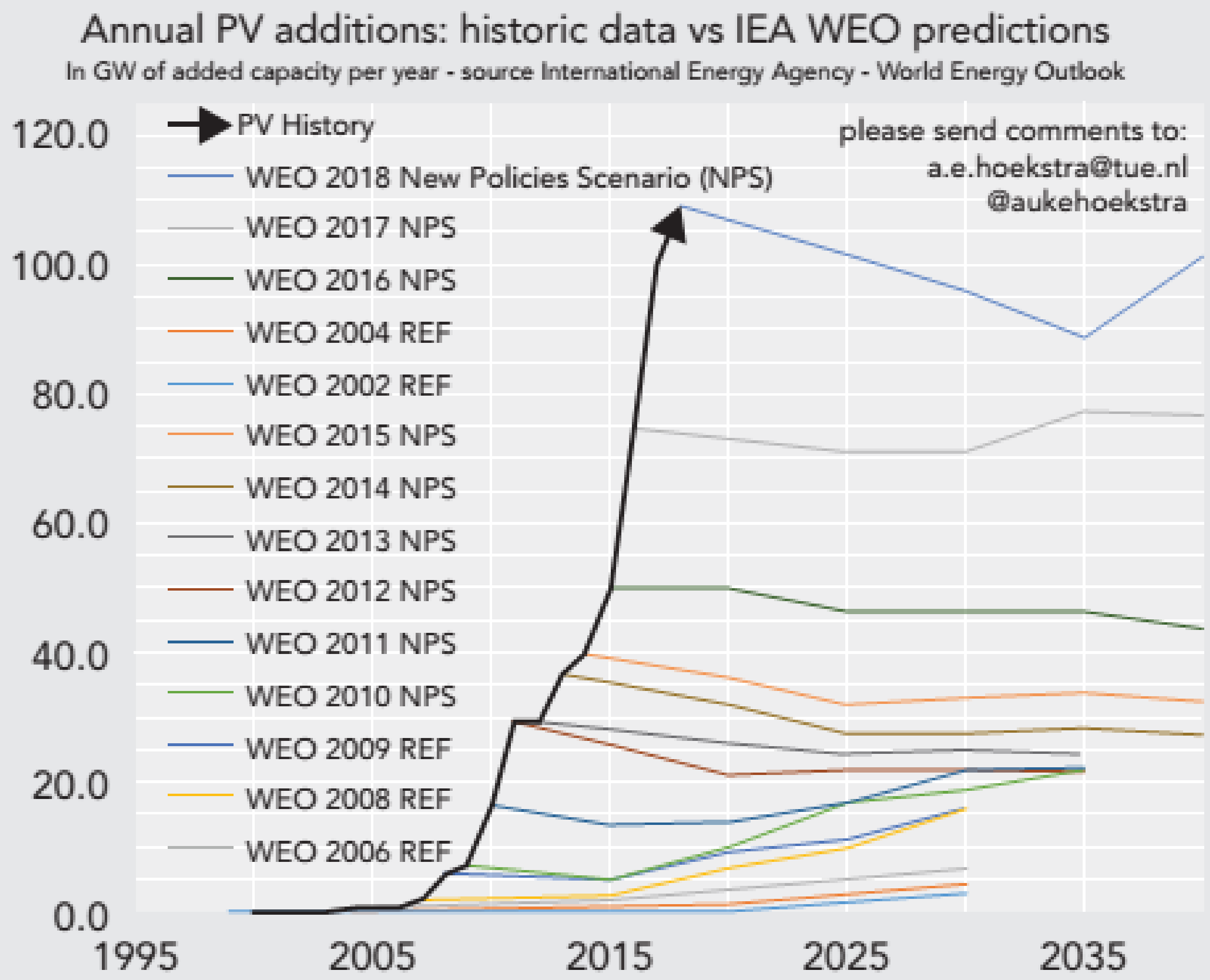

Figure 3

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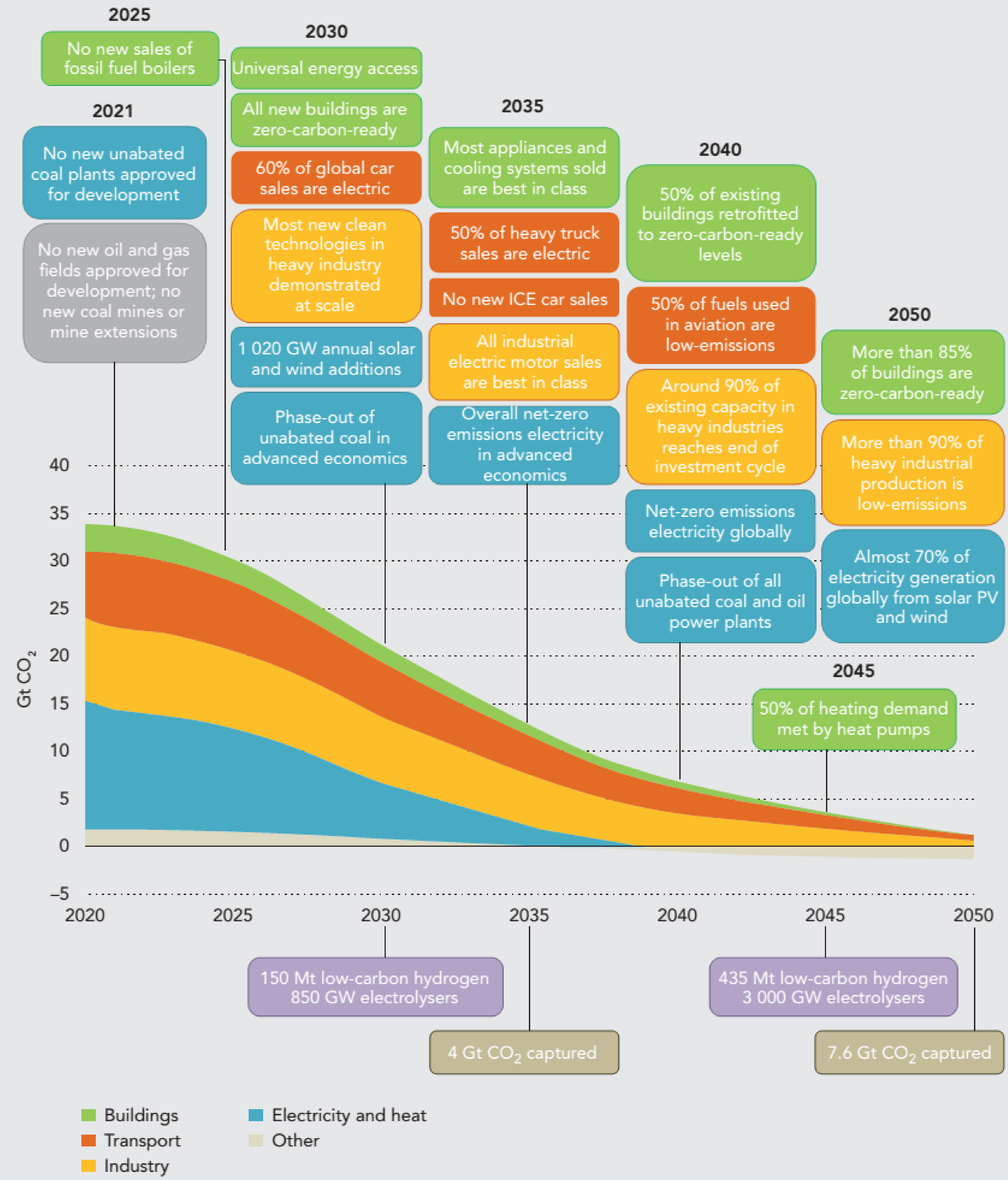
Key milestones in the pathway to net zero



IEA (2021), Net Zero by 2050: A Roadmap for the Global Energy Sector. All rights reserved.

Figure 4

Besides the IEA, there are a handful of other energy transition and climate scenarios in wide use, such as the International Renewable Energy Agency's REmap (from 2016) and Greenpeace's Advanced Energy Revolution. There are also the sector-specific scenarios of the Deep Decarbonization Pathways Project (DDPP), run out of the Institute for Sustainable Development, a French think-tank. A final set of scenarios relevant particularly due to uptake by the financial sector is that developed by the Network for Greening the Financial System (NGFS), which is composed of central banks and financial supervisors. While their materials have been primarily intended for central banking and financial supervision, private-sector financial institutions have also made use of NGFS scenarios. All of these scenarios can then be plugged into various modeling ensembles to estimate impacts. As an example, central banks and private-sector banks making use of the NGFS scenarios have tended to use the REMIND model, a holistic model developed by the Potsdam Institute for Climate Impact Research (PIK). A more detailed analysis of key current reference scenarios is below:

Table 2

Source	**Scenario Name**	**Description**	**Key Dates**	
			Peak *emissions*	***Net-zero*** *emissions*
IEA	Stated Policies Scenario (STEPS)	The Stated Policy Scenario reflects the impact of existing policy framework and announced policy intentions to show how current policy ambitions affect the energy sector through 2040.	2030	Not modelled beyond 2040
	Sustainable Development Scenario (SDS)	The Sustainable Development Scenario is fully aligned with Paris agreement goals, and it holds global temperature rise to below 1.8°C with a 665 probability and without relying on global-level net negative emissions.	2021	Not modelled beyond 2040
	Net-Zero Scenario [2021]	The Net-Zero scenario is aligned with fully net-zero emissions by 2050 across buildings, transport, industry, and power and heat.	2019	2050
IRENA	Planned Energy Scenario	A scenario based on governments' current energy plans and nationally determined contributions	2021	Not modelled beyond 2050
	1.5°C Scenario	A pathway aligned with net-zero emissions by 2050 and thus with maintaining warming below 1.5°C	2021	2050
Greenpeace	Advanced Energy [R]evolution	Pathway to a fully decarbonized energy system by 2050	2020	2050
Institute for Sustainable Development	Deep Decarbonization Pathways Initiative	Country-level pathways for emissions reductions that are consistent with a global 2°C goal	n/a	n/a
NGFS	Orderly Scenario	Climate policies are introduced early and gradually tightened, leading to a steady fall in all greenhouse gas emissions. Warming is likely to be limited to below 2°C.	2020	2060
	Disorderly transition Scenario	Climate policies are introduced later and more abruptly from 2030. Emissions reductions are sharper, leading to higher transition risk.	2030	2050
	Hothouse Earth Scenario	Current policies are preserved, and Paris goals are not met. Emissions continue to grow until 2080, leading to more than 3°C of warming and significant physical risks.	2080	No net zero

Source: IEA (2021), Net Zero by 2050: A Roadmap for the Global Energy Sector.

7.3 Scenario Parameters and Applications to Physical and Transition Risk

The sorts of global-level scenarios and models described above can be utilized to analyze both transition and physical risk. Transition risk and physical risk are on a spectrum—all climate outcomes are expected to have some of both, with drastic emissions cuts (limiting warming to 1.5–2°C) producing high transition risk and moderate physical risk, whereas continued rises in emissions could result in up to 6°C of warming, with high physical risk.

However, the output and usability of global scenarios differs for transition risk compared to physical risk. For transition risk, non-financial corporations or financial institutions typically examine whether their facilities, strategies, and portfolios align with one of the global projected emissions trajectories. Alternatively, they ask the hypothetical question of what if climate policy or other parameters were tightened. For physical risk, emissions trajectories are meaningful to the extent that, when "plugged in" to a physical climate model, it is possible to derive estimates of temperature rise, precipitation, weather extremes, and other phenomena. However, due to the lag in the global climate system, different kinds of scenario analysis that do not use emissions trajectories can sometimes be more useful.

In any case, there are certain common parameters that any scenario analysis has to decide on before starting, no matter what kind of climate risk is being analyzed.

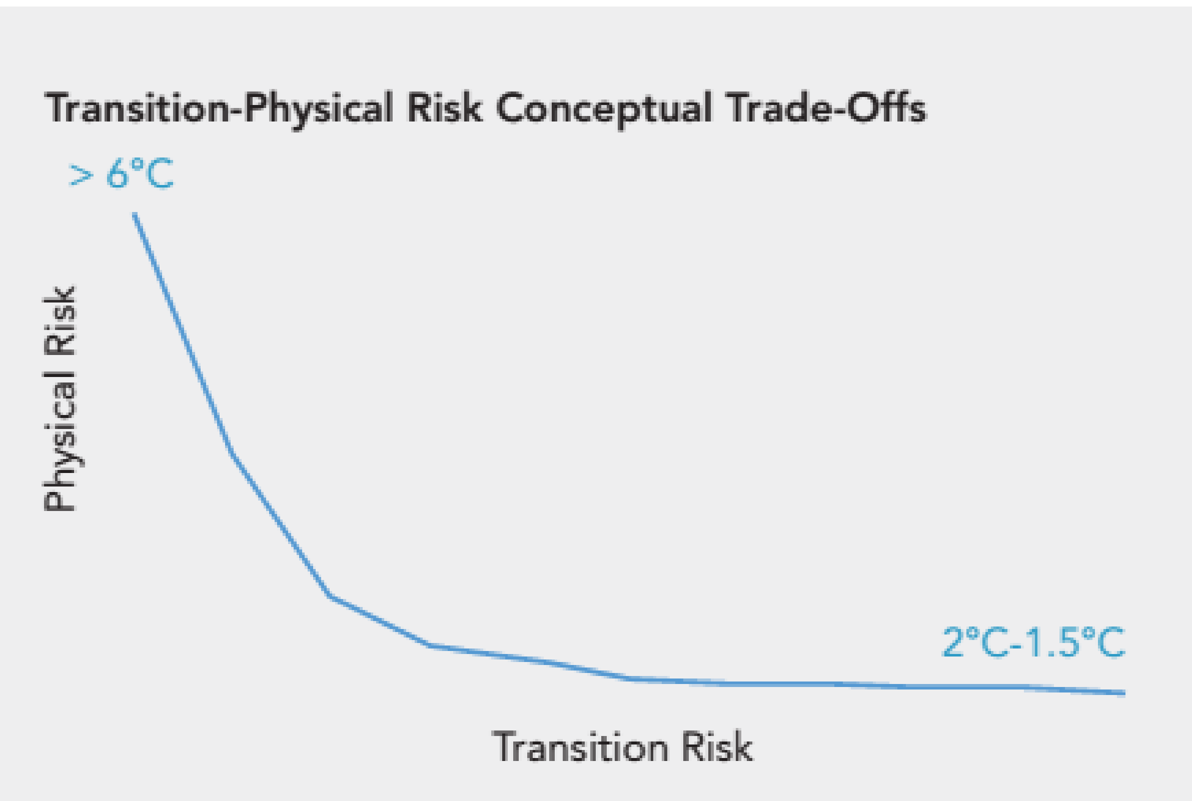


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Figure 5

7.3.1 Choice of Parameters

Scenario analysis starts with a choice of scenario and parameter setting. In many if not most cases, starting with a reference scenario will be sufficient, without needing to build a bottom-up analysis of world energy use by sector from scratch. Nonetheless, to be applicable to the particular firm or situation at hand, scenarios themselves may need to be tweaked, and decisions are required on the desired analysis and outputs.

All climate scenarios have a number of built-in **parameters,** or assumptions. These can range from macroeconomic variables (e.g., GDP growth) to energy demand and the energy mix to policies. Conducting scenario analysis requires analytical choices on scope and methods, including quantitative versus qualitative methods. Scope can also depend on data availability, for example relating to supply chains. Climate scenario **outputs** can range from revenues or costs to asset valuations, such as from assets becoming stranded. The following table, adapted from the TCFD Technical Supplement, highlights key choices to be made (parameters relating only to physical risk are marked in red).

7.3.2 Use of Scenario Analysis for Transition Risk

Transition risk scenario analysis is very closely and directly tied to emissions scenarios, whether the RCPs, IEA scenarios, or custom-made emissions scenarios. After all, transition risk results directly from the speed, pace, and scale of the low-carbon transition. Transition risk is higher when emissions are cut more drastically (net-zero emissions by 2050 scenario versus a current policies or business-as-usual scenario), and when emissions cuts are more abrupt (disorderly versus orderly transition).

Typically, transition risk analysis for a corporation or financial institution involves evaluating whether its own operations, supply chains, and portfolios are aligned with sector-specific and/or global, macroeconomic emissions trajectories. (For more on the different kinds of analysis and how it varies between the financial and non-financial sector see Section 7.4)

On a broad, global-level scale, economic models incorporating climate change and climate policy can be helpful. **Integrated assessment models (IAMs)** are broad-spectrum

Table 3

Parameters/Assumptions	Analytical Choices	Scenario Outputs
• **Discount rates** • **Carbon Price** • **Energy demand and mix** • **Commodity prices** • **Macroeconomic variables**—for example, GDP, employment • **Geographic variation** • **Demographics and employment** • **Technology** • **Policy** • **Climate system sensitivity**—such as the response of climate to given amount of CO_2	• **Quantitative vs qualitative methods** • **Timescale**—2030, 2050, 2100 [2100 only relevant for long-term infrastructure] • **Scope of analysis** • **Data availability** • **Choice of climate hazards**—for example, heat, floods, extreme weather • **Extent of supply chain inclusion** • **Balance of economic, social, and physical analysis**	• **Earnings/profits** • **Revenues** • **Costs** • **Asset valuations**—how badly are assets stranded? • **Investment/capital expenditure** • **Asset allocation** • **Potential impact on productivity** • **Business interruption from physical hazards**
		Source: TCFD Technical Supplement.

models designed to allow analysis of how societal and economic choices affect each other and the natural world, including the causes of climate change. Used extensively by the IPCC, they are also frequently used by academics and sometimes by policymakers and corporations.

The most basic IAMs compare the costs and benefits of avoiding a certain level of warming using highly simplified equations. However, most IAMs in use are far more complex, and they include representations of relevant interactions both among a number of important human systems (e.g., energy use, agriculture, trade) and physical processes (e.g., the carbon cycle). IAMs are most heavily rooted in economics and economic models, meaning they typically assume fully functioning markets and competitive market behavior, and they are calibrated to optimize outcomes as measured by minimizing the aggregate economic costs involved.

IAMs can answer both general questions and specific ones. For instance, "What will the world look like with no climate policy action?" and "What will the world look like if all countries impose a USD 200 tax per ton of CO_2 emissions in 2025?"

For most sectors, or for firms exposed to multiple sectors (such as banks or institutional investors), **sector decarbonization pathways** are a highly useful way of gauging transition risk. Many of these exist, including those laid out by the IEA, the Deep Decarbonization Pathways Project, the Transition Pathway Initiative, or the Science-Based Targets Initiative. These kinds of decarbonization pathways are constructed to be compatible with Paris targets, so a firm making use of these to gauge Paris alignment can mainly restrict itself to the question of gauging whether it is possible for the firm to align with the trajectory (although as with anything, some understanding of underlying assumptions and any model uncertainties will still be helpful and necessary).

There are also external bodies evaluating alignment with various scenarios. For example, the Transition Pathway Initiative, a collaboration between academia and industry, grades publicly listed companies on their level of alignment with Paris-compliant sector trajectories. These assessments can then be used by stakeholders or investors in various ways. Just one example of a secondary application is the family of TPI-linked indices that FTSE Russell, a data firm, offers in which companies are weighted by their transition readiness. Legal and General Investment Management (LGIM), launched the first index-tracking fund linked to one of these TPI indices in December 2020.

Finally, a lot of transition risk scenario analysis is done by **commercial data providers** such as Carbon Delta, Carbone 4, Oliver Wyman, Ortec Finance, NGOs such as 2 Degrees Investing Initiative, and consortiums such as Climatewise, which is part of the Cambridge Institute for Sustainability Leadership. Most of these entities provide detailed data on different asset classes by scenario (RCP) and time horizon for firms to be able to do in-house analysis. One methodology that provides an illustrative example is PACTA, developed by 2 Degrees Investing Initiative, which has seen significant uptake among large global banks (see box).

A final, ambitious approach to transition risk scenario analysis is to build fully original emissions trajectories. Building bottom-up global models of energy demand and emissions, similar to the IPCC or IEA pathways, typically only makes sense for large fossil fuel and commodity firms whose fortunes are closely tied to global changes in the energy mix. Shell, for instance, constructs and periodically updates its own climate and energy scenarios. The latest iteration in the wake of the 2020 COVID-19 pandemic includes three scenarios, "Sky 1.5," which is 1.5°C compatible; "Waves," a

THE PACTA FOR BANKS METHODOLOGY

2 Degrees Investing Initiative, an NGO, has developed a methodology called the Paris Alignment Capital Transition Assessment (PACTA) tool, which has seen considerable uptake both among investors, with its equities and bonds version, and among banks, with the PACTA version on corporate loans, or PACTA for Banks.

PACTA for Banks starts with a bank's financial exposure to physical assets (such as steel or power plants) in the real economy. The methodology then compares economic units of output (e.g., tons of steel, MWh of electricity) to different climate change scenarios, allowing the bank to know which climate pathway its clients are on. Because the analysis uses economic units of output, it is able to make forward-looking projections and assess counterparties against both a "business as usual" and a "Paris aligned" scenario.

The PACTA output metrics look to control two key climate issues:

1. *The absolute production output, and limits, of high carbon technologies. For example, fossil-fuel production in aggregate must ultimately decrease to achieve the goals set out in the Paris Agreement.*
2. *Identifying the production shift from high-carbon to low-carbon production (and the technologies) needed to be compatible with a Paris-aligned world.*

*PACTA for Banks currently covers five climate-critical sectors: **Power, Fossil Fuels, Automotive, Steel, and Cement.** Alignment results are given at the level of each sector (and technology level within those sectors).*

For power, fossil fuels, and the automotive sector, there are viable and clear low- or zero-carbon technologies available, so in these sectors, PACTA uses two metrics to measure alignment:

1. Production Volume Trajectory—this measures the alignment of a loan book and/or client's production volume per technology/fuel against trends prescribed in climate change scenarios.
2. Technology/Fuel Mix—this metric shows the sectoral technology/fuel mix of a loan book and/or client (e.g., what percentage of automobile production a bank finances that is related to electric vehicles, internal combustion engines, etc.) and how this mix should evolve to be considered aligned with various climate change scenarios. This identifies the required shift to low-carbon technologies.

For sectors without clear decarbonization pathways as yet, such as steel and cement, the methodology instead uses the measure of emissions intensity. PACTA can compare the sector-specific emissions intensity of a particular bank's loan book with emissions intensity aligned with climate scenarios.

Source: PACTA for Banks.

disorderly and delayed but quick transition; and "Islands," with a late and slow transition. Perhaps unsurprisingly, both "Sky 1.5" and its predecessor, the 2°C compatible "Sky," assume a much larger continuing role for oil & gas through 2100 than do scenarios drawn up by neutral bodies such as the IPCC or IEA, showing how companies' businesses and interests potentially shape projections.

7.3.3 Use of Scenario Analysis for Physical Risk

Use of scenario analysis for physical risks is significantly different from transition risk scenario planning in multiple ways. One difference is that, to the extent emissions trajectories matter, physical climate models are required as a first step to translate trajectories into physical impacts. However, a second important difference is that, because the climate system responds on a lag, physical impacts until about 2050 are largely "baked in" by current emissions, so emissions trajectories do not matter on the timescale of the next few decades, which is what the majority of policymakers, firms, and investors limit themselves to (Four Twenty Seven, 2019). Finally, because of this, a completely different sort of scenario analysis is sometimes more useful for physical risk—one not driven by global or sector emissions trajectories but an exercise in operational preparedness based on plausible future events.

Physical climate models were originally developed to help scientists understand the functioning and operation of the Earth's climate system. Now, they are an important tool for scenario analysis on physical risk.

The relationship between physical climate models and emissions scenarios goes in both directions. On the one hand, physical climate models are used to calibrate emissions scenarios to make sure that the amount of radiative forcing resulting from the posited emissions correspond roughly to certain temperature targets for global average temperature rise. But on the other hand, these emissions trajectories can then be re-inputted into models to gain an estimate of various hazards.

The growing sophistication of newer climate models allows them to present forecasts with greater granularity, including at the regional level, and for a greater range of phenomena, ranging from heat waves to precipitation patterns. This does come with the caveat, as discussed in Chapter 3, that physical climate models can disagree on the particulars of many hazards when it comes future trends. For instance, essentially all major models predict that precipitation patterns will change going forward due to climate change, but there are disagreements among these models as to the magnitude and particular regions affected.

Both because of the lag in the Earth's climate system and because of the way the physical models are designed, these models give the best accuracy on decadal timescales. Emissions trajectories do make a significant difference in predicting physical impacts in the second half of the twenty-first century, which can matter for very long-term planning, such as for physical infrastructure that is generally expected to last decades. And by 2100, the differences in physical risks between RCPs are very significant (see case study on Ortec).

Another important difference that makes physical risk scenario planning very distinct from transition risk is that physical risk always starts at the facility level. Physical impacts affect specific processes and sites—a flooded factory, a wildfire-ravaged warehouse, an overheated office building—and then these effects cumulate upward through ownership supply and investment chains. Thus, as far as facilities are concerned, both non-financial firms and financial ones are forced to consider physical risk as an operational risk. For transition risk, industrial firms can principally examine their own facilities or compare performance to sector benchmarks, and even financial firms can use emissions data for just a few key emissions-intensive sectors to get an estimate portfolio alignment. Meanwhile, for physical risk, all sectors and a wide range of assets and facilities are potentially affected.

As discussed in Chapters 3 and 6, examining facility-level physical risk requires having detailed data on hazards, exposure, and vulnerability, including adaptive capacity, which many firms choose to source from commercial data providers such as Four Twenty Seven, Carbone 4, or Trucost, whereas others evaluate these in-house.

Finally, and importantly, the combination of the lower importance of emissions scenarios for physical risk in the shorter term (through 2050) and of physical risk's operational nature means that the type of scenario analysis that

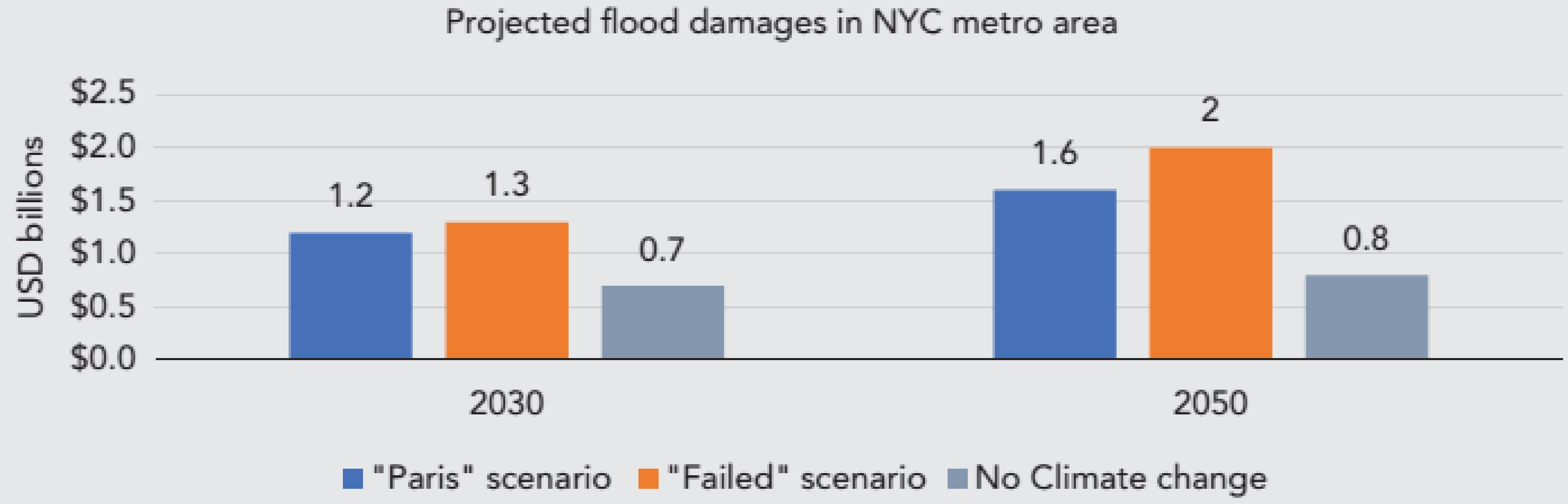
CASE STUDY: VERY LONG-HORIZON PORTFOLIO PHYSICAL RISKS—ORTEC FINANCE

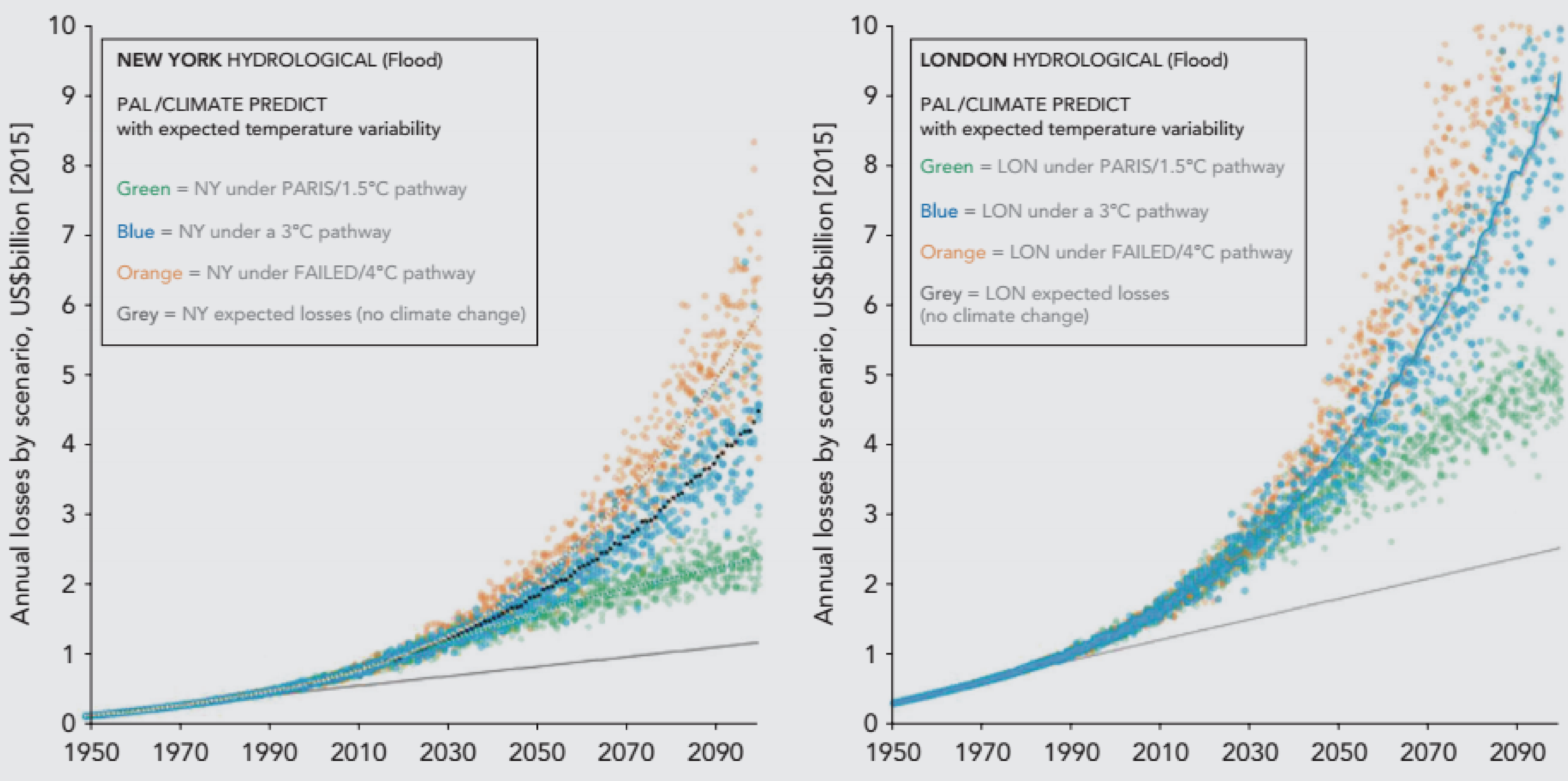
Ortec Finance, a consulting firm, has an in-house model called ClimatePREDICT specializing in projecting extreme weather risk on decadal timescales. Specifically, the model forecasts the increase in frequency as well as the financial impact of climate-related extreme weather risk to physical assets and economic growth. It does this year-by-year and across various peril classes, covering over 120 countries.

In a case study, Ortec modeled losses from extreme weather events linked to climate change under a 4°C "failed transition" pathway and a 2°C "Paris compliant" pathway.

On a timescale of the coming decades, the difference in losses is not that great between scenarios. For the New York City metropolitan area, losses from hydrological (flooding) events are predicted to be USD1.2 trillion in 2030 under a "Paris" scenario and USD 1.3 trillion under a "failed" scenario. The difference between the two is somewhat greater in 2050, but the two scenarios are still much closer to each other than a counterfactual, hypothetical baseline with no climate change (see bar chart).

However, when the outlook is extended to the end of the century, differences between scenarios diverge markedly. In New York by 2100, annual flood losses in a "failed transition" 4°C scenario are expected to be triple those in a "Paris compliant" scenario.





Reprinted with permission of Ortec Finance, Climate PREDICT solution (www.climatepredict.app).

Figure 6

tends to be conducted for physical risk is, in fact, much closer to the original tradition of scenario analysis as pioneered by Herman Kahn or Shell. That is to say, plausible scenarios of physical impacts can be drawn up that can then help prepare for impacts. For this sort of planning, physical climate models can help to an extent in pinpointing vulnerable areas. But they cannot predict incidence precisely enough to be of use for forward planning, especially not for acute physical hazards (e.g., when a flood will hit). Therefore, using scenarios that are based on historically plausible circumstances, especially of the types of hazards that are expected to increase in frequency and severity with climate change, can provide an excellent way to build preparedness and resilience (see Section 7.4.2).

7.4 Scenario Analysis Use Cases: Corporate

This section examines how climate scenario analysis is used for different corporate use cases, ranging from strategy-setting and stakeholder communication to preparedness planning meant to increase resilience. This section focuses on corporate actions applicable to all kinds of corporations, financial and non-financial. Section 7.5 then examines the use of scenario analysis specifically in financial and investment contexts.

7.4.1 Strategy and Stakeholder Communication

An important reason for firms to engage in scenario analysis is for setting corporate strategy and communicating that strategy to investors and other stakeholders. Much of the impetus for this use of scenario analysis has come from the wide uptake of TCFD recommendations, which many firms have signed onto and which shareholders increasingly expect, or regulators require. Thus, many scenario analyses have been published in firms' TCFD-compliant climate change reports, where many of the case studies in this chapter are sourced.

While communication at first may sound like a public-relations exercise, this use of scenario analysis in fact has important consequences. If companies do not make climate change plans and conduct analyses that are seen as credible and thorough, investors can come after companies. A vivid example occurred in May 2021, when an investor campaign, spearheaded by an activist hedge fund, Engine No 1, voted to place two independent directors on the board of ExxonMobil, the American oil & gas giant, against management's wishes. Increasing numbers of institutions have committed explicitly to the alignment of their operations and strategies with Paris agreement goals and/or more-precise targets, such as net-zero emissions by 2050. But these institutions cannot make these changes in practice without conducting scenario analyses and communicating these analyses clearly to investors.

Another important reason why scenario analysis matters for companies is self-interest—scenario analysis can help chart opportunities and future demand for products. A good example is BHP Billiton, a mining and fossil-fuel firm, which uses four scenarios to model differences in commodity demand over the coming three decades (see box).

7.4.2 Operational Risk and Resilience Planning

Another important reason for firms to conduct scenario analysis is to mitigate operational risk and improve preparedness and resilience. A company can sketch out scenarios where its crucial operational or supply chain assets are hit by transition or physical risk-related shocks (e.g., a sudden large carbon tax hike, or a huge storm) and then assess how materially this would affect the business.

These can be based on plausible but not realized events (as with the Citi case study) or recent true events, and are equally applicable to financial and non-financial firms, as all types of firms use at least some physical facilities and rely on some network of suppliers and customers. This type of scenario analysis is notably good for addressing the potential for business disruption. Climate-linked business disruption relating to physical climate risk is not a distant future prospect but is already occurring. Examples include the 2011 Thai floods or 2020–2021 Taiwanese drought, both of which disrupted semiconductor production, and the 2019 European heatwaves and drought. The latter forced production pauses in certain German industries, including at BASF chemical plants, due to the inability to transport materials by barge on the Rhine with its historically low water levels.

BHP BILLITON SCENARIO ANALYSIS—EXCERPTS

Scenario analysis approach

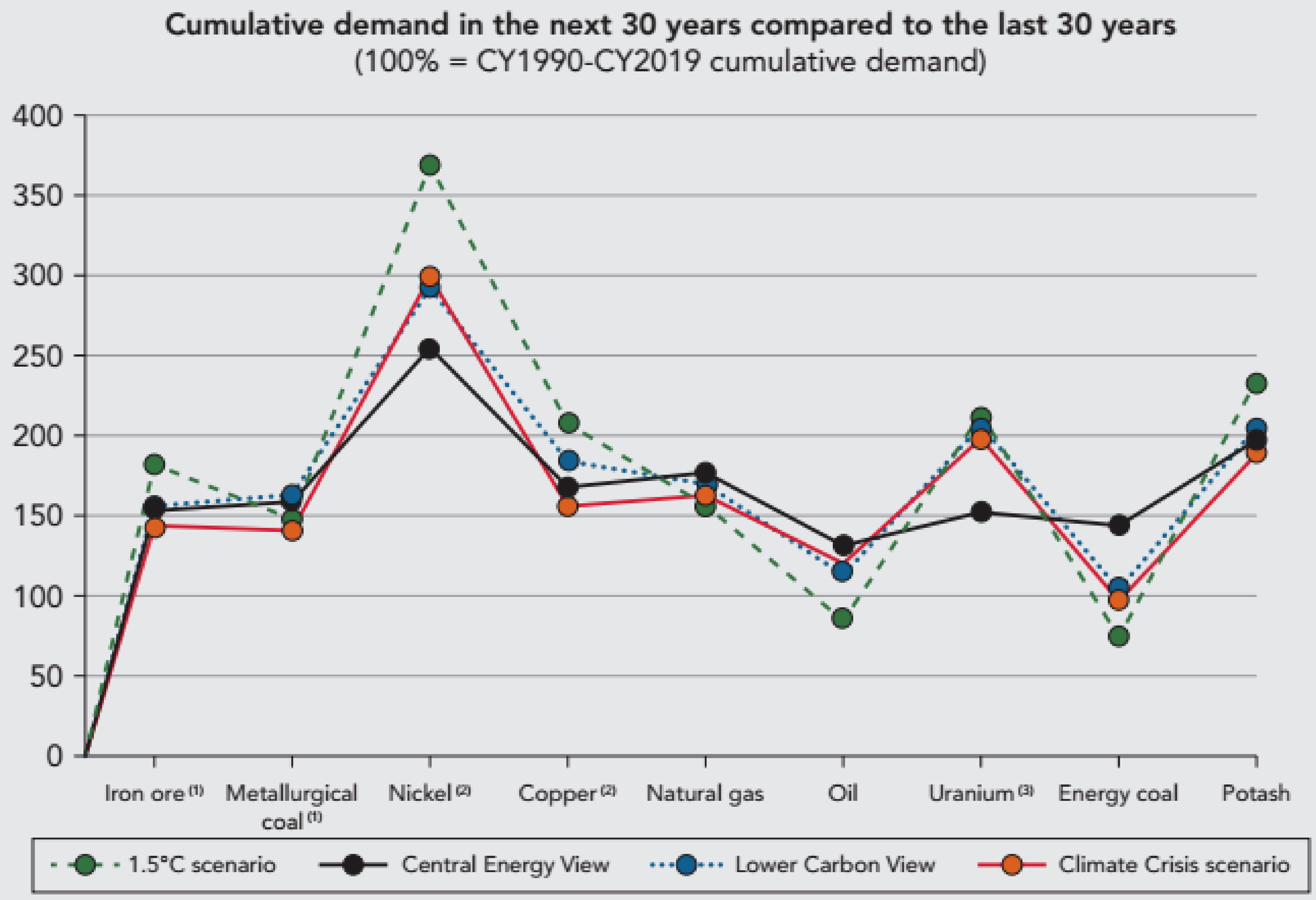
BHP develops planning cases to inform our strategic choices and the timing of their execution, and to underpin our rigorous annual corporate planning process. These planning cases consist of plausible commodity-specific forecast ranges (high, mid and low cases) that are developed through in-depth, rigorous bottom-up analysis. […]

Scenarios do not constitute definitive outcomes for us. Scenario analysis relies on assumptions that may or may not be, or prove to be, correct.

Scenarios:

- ***Central Energy View** reflects existing policy trends and commitments, and tracks to approximately 3°C temperature increase above pre-industrial levels by 2100*
- ***Lower Carbon View** tracks to approximately 2.5°C temperature increase by 2100 and accelerates decarbonization trends and policies, particularly in easier-to-abate sectors such as power generation and light duty vehicles*
- ***Climate Crisis** scenario has strong growth with limited climate action for a decade and a half, followed by a climate crisis which precipitates an extremely steep decarbonization trajectory, societal turmoil and low GDP growth*
- ***1.5°C scenario**, which aligns with the goals of the Paris Agreement and requires steep global annual emissions reductions, sustained for decades*

Source: BHP Climate Change Report 2020.



(1) Iron ore and Metallurgical coal demand accounts for Contestable Market = Global seaborne market plus Chinese domestic demand
(2) Nickel and Copper demand references primary metal
(3) Nuclear power was used as a proxy for historic cumulative demand for Uranium

Figure 7

CASE STUDY: SCENARIO ANALYSIS FOR PHYSICAL CLIMATE EFFECTS ON OPERATIONS—CITI

The large US-based bank Citi is more concerned with operational risk than many other banks because of its large retail banking division as well as its wide geographical footprint. Citibank recognizes that the physical impacts of climate can cause business disruption.

In 2020, Citi conducted an operational/physical risk scenario assessment exercise focusing on the impact of extreme weather events on two large employee centers in the United States, in Tampa, Florida, and New York City.

The bank selected these locations due to their strategic importance and exposure to hurricane (cyclone) risk based on previous climate risk mapping. It then developed three scenarios with different probabilities of occurrence that were designed to be plausible but severe, ranging from the most likely (1 in 25 chance) to less likely (1 in 100) to least likely to occur (1 in 1000). The scenarios were as follows:

***1/25: Tropical storm affects Tampa, Florida, office complex** → Some damage to facilities*

***1/100: Tropical storm and then Category 5 hurricane affect Tampa, Florida, office complex** → Facilities are left inoperable and must be rebuilt*

***1/1000: Tropical storm and Category 5 hurricane affect Tampa, Florida, office complex and <u>simultaneously</u> a tornado hits the New York City headquarters** → Facilities are left out of commission and require repair (NYC) or complete rebuilding (Tampa)*

Due to data limitations, these probabilities were based mainly on historical climate patterns, and thus do not account for expected increases in frequency or severity due to climate change. The scenarios also did not incorporate the impacts to local infrastructure (e.g., electricity, transportation networks), but only to Citi facilities.

After completing the scenario analysis, the bank estimated that significant physical and financial damage would be incurred. Nonetheless, Citi concluded that there would "not [be] a material impact to our operational resilience." In particular, the bank cited the successful example of temporary work-from-home arrangements during the COVID-19 pandemic as a successful coping strategy in case offices are damaged or destroyed by climate-exacerbated weather hazards.

Source: Finance for a Resilient Future: Citi's 2020 TCFD Report.

7.5 Scenario Analysis Use Cases: Finance & Investment

This section examines how climate scenario analysis is specifically useful for financial firms, notably for portfolio-level analysis and stress testing and for ex-ante integration into investment decisions.

7.5.1 Portfolio Analysis and Stress Testing

An important use case of scenario analysis in the financial sector is to examine portfolio-level exposures, and gauge how these would vary in different climate outcomes (i.e., scenarios). Stress testing, a practice that has been in wide use by financial regulators for over a decade, has now been taken up by both the public and private sectors. As regulators such as the Bank of England start implementing climate stress tests, an increasing number of financial institutions, especially banks, are choosing to voluntarily conduct stress tests internally and not just when mandated by a regulator. Often, the results are then published and the results are used as a way for institutions to communicate their soundness and solid ERM practices to their own investors and other stakeholders. This is exactly what HSBC, a large global bank, has done with a transition risk stress test on its loan portfolio (see box).

7.5.2 Ex-Ante Investment Integration

Although stress testing and portfolio-level analysis of climate exposures is increasingly well-established, *ex ante* integration of climate scenarios into investment processes is a newer phenomenon. Analogous to ESG, where integration has followed on from exclusion or ad hoc analyses (as covered in Chapter 5), more proactive use of scenarios in investment decision-making does seem to be the next frontier in investment management. Some early movers have already announced moves in this direction (see box). Having scenario analysis as part of the toolkit of portfolio managers and other investment decision-makers can potentially preempt undue exposure to climate risk or serve as an early indication for where investment firms can focus engagement efforts.

CASE STUDY ON USE OF SCENARIOS FOR TRANSITION RISK: HSBC

*In 2020, HSBC, a global bank, used a scenario analysis stress testing pilot to examine its portfolio exposure to six sectors and sub-sectors highly exposed to high transition risk. To do so, it used the NGFS reference scenarios of an **orderly** and **disorderly transition** and of a **hothouse world**.*

*The sectors examined were **automotive, construction, chemicals, metals and mining, oil & gas, and utilities** (see schematic, which illustrates the level of risk the bank is exposed to within each sector portfolio in different climate scenarios).*

In the automotive sector, the analysis was run on auto manufacturers, with the key scenario driver being the transition from internal combustion to electric vehicles (EVs). In all scenarios, high EV adoption is expected, with an even quicker uptake in the disorderly transition, which has higher carbon taxes.

In chemicals, some are very emissions-intensive, such as ammonia and methanol, while others are not. Carbon pricing affects the chemicals sector in the scenarios, but so does growth in demand due to economic expansion.

Oil & gas is expected to be hit with declining demand for fossil fuels in both the orderly and disorderly scenarios. In the former, gradual increases in carbon taxes and development of carbon removal (negative emissions) technologies allows the sector to adjust more smoothly than in the disorderly scenario where high carbon taxes are suddenly imposed.

In the power generation sector, utilities differ significantly in their current electricity mix and their ability to transition. Nonetheless, the sector is actually expected to perform better in a disorderly transition scenario, as opposed to an orderly one, due to a disorderly, abrupt transition increasing electricity demand and prices.

Adapted from HSBC Holdings PLC Task Force on Climate-related Financial Disclosures ('TCFD') Update 2020.

Consolidated transition risk heat map across six high transition risk sectors – illustrative results of sub-sectors

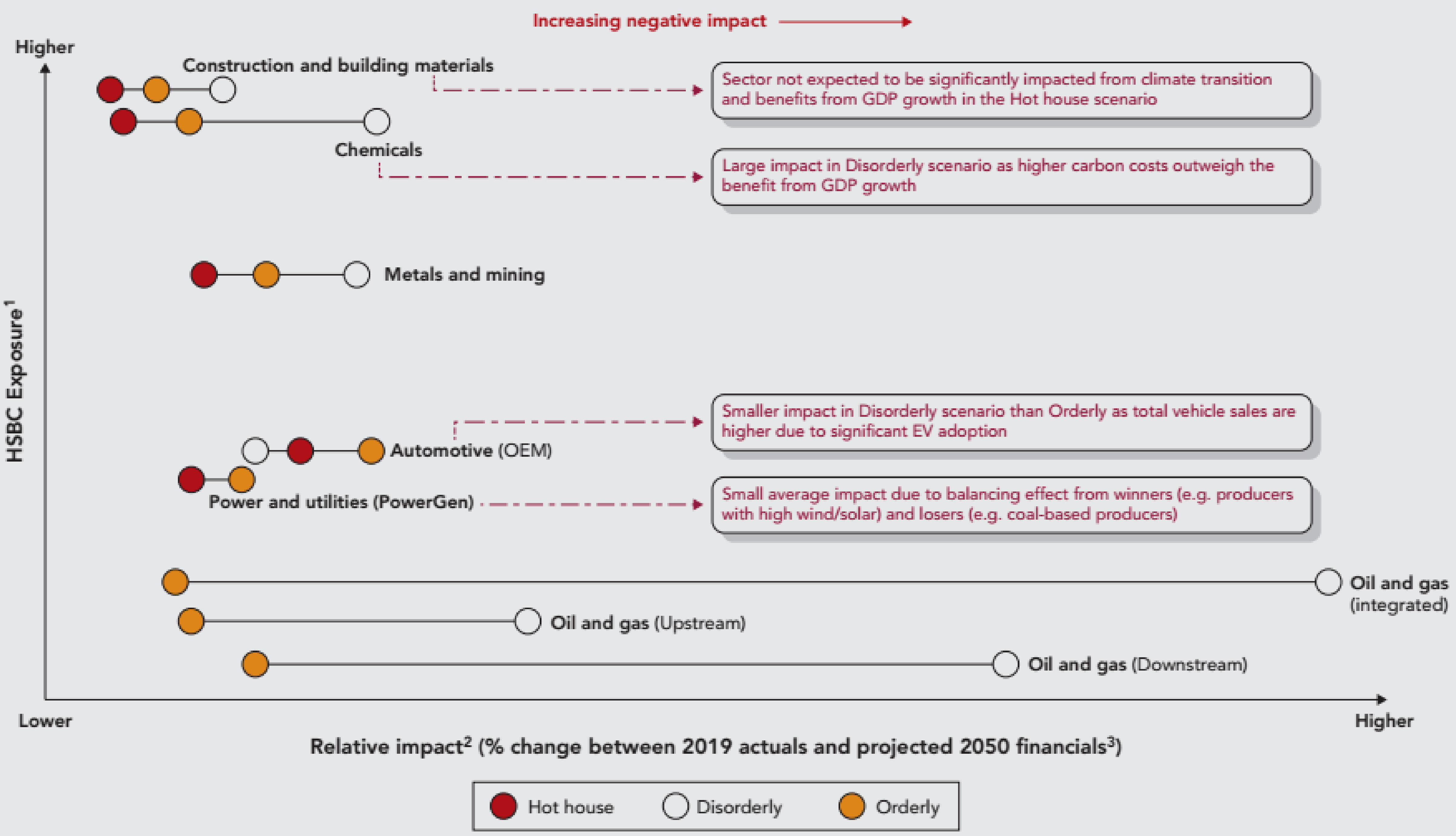


Figure 8

CASE STUDIES: INTEGRATION OF SCENARIO ANALYSIS INTO ASSET MANAGEMENT

Abrdn (formerly AberdeenStandard)

In 2021, Abrdn, a UK asset manager, set out how it intends to integrate its in-house climate scenario work into its investment activities:

"In the coming months [as of Feb 2021], we will fully integrate our climate-scenario framework and insights into our business strategy […] This will include the following:

a. Integrating the results into active stock selection by asking critical climate-related research questions that are informed by our scenario analysis. […] This in turn will allow us to construct portfolios that are resilient to different plausible climate pathways.

b. Embedding scenario analysis into our approach to stewardship. Where material climate risks are identified, we will engage with companies to understand what actions they are taking to mitigate them and encourage firms to undertake their own analysis. […]

c. Fully integrating climate risk and opportunity into our strategic asset-allocation framework […]

d. Developing a wide range of innovative climate-change (including net zero) solutions for our clients."

Legal & General Investment Management (LGIM)

In October 2020, LGIM and Baringa Partners, a specialist in climate and physical risk analysis, announced the co-development of a bespoke climate risk framework, Destination@Risk. This framework is intended to allow

- *LGIM to quantify physical and transitional risks of climate change within its investment portfolios using these proprietary climate scenarios.*
- *the degree of alignment at the company level to coincide with Paris goals—preliminary data and initial analysis of a sample set of 2,000 companies done for the launch announcement showed that the majority were not aligned to Paris.*
- *these scenarios and measures of alignment to be fully integrated into all LGIM's investment activities globally through a "climate dashboard."*

Source: Climate Scenario Analysis: A Rigorous Framework for Managing Climate Financial Risks and Opportunities, Feb. 2021.

7.6 Conclusions

This chapter has sought to demonstrate the utility, and indeed the necessity, of using scenario-based modeling to properly understand the impact of climate change. The space does have a lot of background knowledge and terminology to wade through, as a lot of the groundwork, as well as global-level scenarios, were originally developed by scientists for scientific use. The reason to become familiar with representative concentration pathways (RCPs), shared socioeconomic pathways (SSPs), and integrated assessment models (IAMs) is because they have broadened from their original scientific use cases to be the mainstay of anyone, including corporations or financial institutions, seeking to understand climate change and integrate climate risk into investment and strategic decisions.

But it is equally important to recognize how scenario analysis, to be useful to non-financial and financial firms, must be done differently for transition and physical risk, and for different use cases. Transition risk analysis does typically mean starting with global reference scenarios on emissions trajectories, but it also requires the use of sector-specific pathways and firm-specific information. For physical risk, global scenarios matter only for very long-term planning because the significant physical differences between emissions scenarios only really manifest after 2050, in the second half of the century. Instead, the use of scenario planning for corporate contingency planning can be more fruitful.

While corporations of all kinds can and do use climate scenario analysis to decide on strategy, communicate with stakeholders, and increase preparedness, financial firms in particular can also benefit from the use of scenario analysis for portfolio stress testing and as an input for investment decision-making.

REFERENCES

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W. J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver, A. J., & Wehner, M. (2013). Long-term Climate Change: Projections, Commitments and Irreversibility. In T. F. Stocker, D. Qin, G.K. Plattern, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Four Twenty Seven. (2019). *Demystifying Climate Scenario Analysis for Financial Stakeholders*. http://427mt.com/wp-content/uploads/2019/12/Demystifying-Scenario-Analysis_427_2019.pdf

Wilkinson, A. K., Roland. (May 2013). Living in the Futures. *Harvard Business Review*.