CHAPTER 4

Mapping Out When and Where Climate Risk Becomes a Credit Risk

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Introduction

The growing attention on climate risk by the financial system has resulted in an increasing focus on definitions and reference points for financial institutions. As a result, the Financial Stability Board created a taskforce that published recommendations on climate-related financial disclosure (Financial Stability Board 2017). The taskforce differentiates between the two main types of climate risk: transition risk and physical risk. This chapter discusses each in turn and how they relate to potential credit risk.

Credit risk analysis is concerned with assessing the ability of an entity to continue servicing its debt. It results in a focus on factors which have a material financial impact on the creditworthiness of a debt issuer, for example, related to profitability and leverage ratios. Separate to this type

The views expressed in this chapter are those of the author, and not necessarily those of Moody's.

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of analysis, there is a growing interest in financial products that demonstrate a positive or reduced impact on the environment and society. These products are looking at the impact in a different direction—the external impact of an entity—which may or may not have any financial significance for its creditworthiness. Indeed, the distinction is captured in the concept of 'double materiality', which is applied as an example in the European Union's proposals for non-financial reporting (European Commission 2017). The continuing presence of environmental externalities demonstrates that in many situations, the polluter is not made to pay, and therefore having a large negative impact on the environment does not necessarily result in a material financial cost. Not all environmental impacts will have a consequence for credit risk.

Whilst there is some crossover in terms of the approaches taken to identify climate risks, it should be noted that these risks can manifest themselves in different parts of the capital markets when viewed through an investor lens. Hence, the focus and interests of debtholders may not always align with those of the shareholders in the same company. This situation can be explained by the different exposure to potential upside and risk that results from holding equity versus bonds. For example, an equity-holder may be supportive of increasing borrowing to grow long term; however, a bondholder will consider the increased leverage from taking on extra debt and the increased risk that a borrower will be unable to make interest payments.

From a climate risk perspective, exposure and risk may also be concentrated in different areas. For example, equity investors may prioritise the companies with the largest market cap and the largest emissions as a focus for engagement. These were major factors in determining the companies included in the Climate Action 100 list being used by a coalition of investors to co-ordinate engagement on climate risk (e.g., Climate Action 100 2017). Fixed-income investors may be more concerned with smaller companies with lower credit ratings, which are more susceptible to default and would result in higher losses in the event of a default.

Fixed-income investors should also consider how risk may be transferred between asset classes. If there is an expectation that public entities will bail out the private sector actors, then it should be reflected in the risk analysis. This situation occurred in Alberta, Canada, where Kinder Morgan, the developer of a proposed pipeline, has achieved a reduced risk profile and lower leverage by selling the Trans Mountain project to the federal government for CAD$ 4.5 billion when opposition made progress impossible in 2018 (Morgan 2018). As a result, the risk became elevated for the Canadian government, which took over the costs of project construction, and for the province of Alberta, which has future royalties at risk.

This type of risk transfer also demonstrates why an overarching framework is needed to capture climate risk instead of analysts looking at issuers in isolation. The UNEP (United Nations Environment Programme) Finance Initiative worked with a number of banks to develop a high-level framework that lays out a useful approach for understanding the potential exposure of a lending portfolio to climate risk, which includes transition scenarios, portfolio impact assessment, and borrower-level calibration (UNEP Finance Initiative 2018). These banks are now trialling these approaches to test if they are fit for purpose.

Consideration of climate risk for fixed-income investors has come later than for equity investors. As a result, there is limited evidence regarding how climate risk relates to credit risk. Firstly, many studies are based on 'ESG scores' (environmental, social, and governance), which do not necessarily focus on the most material credit issues, but include metrics relating to historical impact (e.g., CO_2 emissions), governance (e.g., corporate policies on climate change), or disclosure (e.g., the information published on these issues). The evidence available largely indicates that there is no strong correlation between these environmental scores and credit indicators, let alone any clear causal relationship (e.g., see Barclays 2018). The picture is further confused by scores that combine the environmental, social, and governance factors, which may in fact cancel each other out.

Secondly, the types of risk analysed present data challenges compared to established financial metrics with decades of historical data, such as debt default rates. Transition risk, by its nature, implies a change occurring. This definition means that using three-year trailing average performance as an indicator is not going to designate when the transition is starting. Historical physical climate change data is available and has been applied to some financial products, such as natural catastrophe insurance. However, the data can present challenges in terms of getting the granularity and predictive capacity desired. The distribution of physical climate events that occur in consecutive years has no respect for the long-term average probability statistics.

Systems for addressing climate risk can provide frameworks for identifying and understanding relative exposure to the different types of risk. Yet, no crystal ball can predict exactly where and when climate risks will impact the market. Financial regulators are also working to understand how to assess the systemic climate risk to markets and the exposure of financial institutions, with many central banks and regulators now members of the Network for Greening the Financial System (Network for Greening the Financial System 2019). As scrutiny is increasingly placed on this area, so are the tools being developed to meet the requirements of the regulated financial sector.

Identifying Transition Risk

Transition risk relates to the policy, technology, and market changes that accompany the shift to a low-carbon economy. These categories are the three main transmission channels through which analysts think about transition risk. The pace and scale of this transition is uncertain, which influences how credit analysts may think about it.

History tells us that sectors undergoing a transition often underestimate the speed at which it happens, as evidenced by incumbents sticking to the same strategies, perhaps in denial of the changes occurring around them. Whilst most transitions do not manifest as overnight wholesale changes, a fundamental switch in the direction of travel can be enough to pose serious challenges. For example, a market moving from growth to decline requires a different strategy, can affect marginal producers significantly, and may weaken prices across the board. This dynamic also makes capital investments questionable and may lead to difficult decisions about how and when to deal with overcapacity.

US Coal Mining Sector Example

To take the US coal mining sector as an example, the industry failed to recognise a structural decline in demand for its product. This decline occurred because of policy factors (emissions standards), technology changes (cheaper renewables), and market factors (cheaper shale gas). Disclosures to investors at the time continued to talk up their assets and identify export markets as a plan B. The outcome was that most of the large US pure coal mining companies filed for bankruptcy protection in 2016, leading to capital restructuring (Moody's 2019b).

Table 4.1 provides the credit rating migration over time as the structural challenges impacted the US coal mining industries. Most companies saw their credit ratings bottom out in 2016, and only Arch Coal achieved

Table 4.1 Moody's credit ratings for US coal mining companies 2014–2018

Company	*Moody's credit rating over time*		
	2014	*2016*	*2018*
Arch Coal Inc.	B3	C	Ba3
Bowie Resource Partners LLC	B2	Caa1	Caa1
Cloud Peak Energy Resources LLC	Ba3	Caa2	Caa1
Foresight Energy LLC	B2	Caa3	B3
Murray Energy Corporation	B2	Ca	B3
Natural Resource Partners LP	B1	B3	B3
Peabody Energy Corporation	Ba2	Ca	Ba3
Westmoreland Coal Company	Caa1	Caa3	Caa3

Source: Moody's Investor Services (2018e)

the rating it had in 2014 again by 2018. The companies had to file for Chap. 11 bankruptcy protection and/or to implement significant restructuring in order to continue operations.

The degree of financial impact the companies experienced depended on many factors, including:

- the degree of exposure to metallurgical coal for steel production, which diversified risk;
- the relative profitability/margin of the production;
- the location of the production and potential for exports; and
- the degree of existing leverage from merger and acquisition (M&A) activity in recent years.

This example also demonstrates that if the transition is not recognised, then an industry with concentrated risk can very quickly start defaulting on its loans.

Transmission Channels

As demonstrated by the US coal mining sector example, there are three primary ways in which carbon transition risk can manifest itself.

Policy: The regulation of emissions or the government support of low-carbon alternatives can create policy risk for carbon-intensive activities. Different mechanisms provide varying levels of certainty in terms of the emissions outcome, with market-based measures less certain. The most definitive policy mechanisms indicate a phase-out of a particular activity over a given timeline. For example, in a number of European countries, governments have indicated the year by which coal will cease generating power. This may in fact result in earlier closures, as there is little incentive to keep investing and cheaper alternatives are already available. Carbon pricing mechanisms provide a market signal; however, whether this signal triggers a switch in generation depends on the relative commodity prices for coal and gas, other policy measures, and the overall emissions cap being applied. It may also be necessary to consider how easy it is for the emitter to pass this cost down the value chain, reducing the impact on its own margins.

Support for the sales of electric vehicles through purchase subsidies or production targets represents a risk for those who delay developing these technologies. Emissions regulations across China, Europe, and California give extra credits for electrified vehicles, which is rewarding those who have invested early. This example demonstrates how environmental regulation is starting to require major capital investment or impose material penalties for non-compliance. Moreover, a significant revenue stream for Tesla is sales of emissions credits to conventional auto manufacturers, which is an extra revenue source derived from being a leader in producing electric vehicles. These policy measures are therefore not negative financially for all participants in the market.

Technology: It is difficult to predict the disruptive force that is technology. Most analyses will focus primarily on relative cost to ascertain when a technology might start gaining market share or putting pressure on incumbents. Technology can also surprise markets when it changes something fundamental about consumers' behaviour and consumers' desire. There is some evidence suggesting that the energy sector and energy modellers have been behind the curve in projecting how fast renewable energy costs might fall (Carbon Tracker 2015, 2017b).

For example, the cost of technologies such as lithium batteries, solar panels, and wind turbines has fallen faster than many expected, leading to a faster uptake and earlier deployment. This progress is critical for cost optimisation models of the energy system, which will select the cheapest option to meet energy demand. Figure 4.1 shows how the cost of solar photovoltaic units has fallen by 88% over the last nine years (Lazard 2018).

It is important to recognise that the energy transition is not just about doing the same thing in a different way; it is also about doing things better or through different relationships. This is where traditional sector

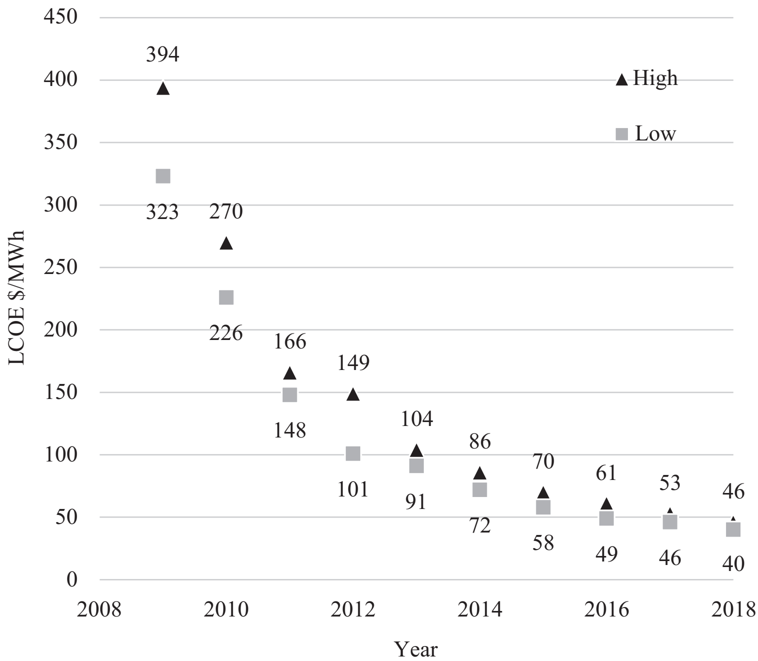

Fig. 4.1 Unsubsidised solar photovoltaic levelised cost of energy (LCOE). (Source: Lazard (2018), modified representation)

classifications start to blur, as energy solutions may come from broader technology or communications companies seeking to leverage their customer base or datasets, rather than from within the incumbent sector. Alongside these disruptions appear more traditional and incremental improvements in efficiency and existing technology that are less likely to disrupt markets, but can contribute to weakening demand and reduced emissions over a longer period.

Market: Ultimately, consumer preferences can drive a number of markets, which are hard to predict. Consumer choice can both accelerate and hinder the low-carbon transition. Indeed, reputational risk is increasingly linked to environmental performance, and customers can increasingly select 'greener' options. The maturity of the market is also important to consider, as established markets with existing infrastructure may take longer to turn over the legacy in place. Growth markets where particular products/services are not established can see more rapid take-up of new solutions. Large institutions, whether public or private, can also act as buyers who want to reduce their own carbon exposure. There are increasing volumes of power purchase agreements being signed by corporations or local governments wishing to secure their own low-carbon power supply. This kind of contract certainty with large credit-worthy counterparties also reduces the risk for low-carbon projects. Project finance lending in the power sector has seen ten-year cumulative default rates lower for green (5.7%) than for non-green (7.5%) projects in recent years as a result of these kinds of structures as the low-carbon transition gains traction (Moody's Investor Services 2018a).

It can be difficult to separate these three transmission channels in practice, as they are mutually reinforcing. The driving factor may depend on the stage a sector is at in terms of the cycle of policy supporting technology, which makes it cheaper and in turn increases consumer uptake. The other form of transition risk on the horizon is climate liability, with growing numbers of lawsuits being brought against government and corporate actors. This event risk has yet to manifest itself in most jurisdictions as legal systems process these new types of claims.

Sector Prioritisation

From a credit perspective, investors and rating agencies think about different types of debt issuers and the characteristics they have. Rating agencies have different methodologies for different asset classes and for different corporate sub-sectors. The approach to thinking about the credit implications of climate risk for a sovereign debt issuer might be very different to that applied to a large corporation and different again for an infrastructure project. In each case, it is possible to prioritise types of issuers or sectors which are exposed to higher levels of risk.

Sovereign risk: As would be expected, more macro variables are being considered for assessing sovereign risk than for individual corporations. For example, some sovereigns are reliant on fossil fuel royalties and exports to contribute to GDP. The limited diversification of these economies leads them to be more exposed to transition risk. Using scenarios here can help to understand the potential downside to business if a more rapid transition occurs (Moody's Investor Services 2018d).

Table 4.2 shows the impact on the sovereign credit ratings for oil and gas exporting countries when applying the International Energy Agency's Sustainable Development Scenario. The shaded areas indicate where a

Table 4.2 Moody's estimated sovereign credit ratings under a low-carbon scenario

Countries	Current	2025	2030	2040
Angola	B3- Caa2	B3- Caa2	B3- Caa2	Caa2 - C
Azerbaijan	Ba1 - Ba3	Ba1- Ba3	Ba1 - Ba3	Ba3 - B2
Bahrain	Ba2 - B1	Ba2 - B1	Ba2 - B1	Ba2 - B1
Republic of the Congo	Caa2 - C	Caa2 - C	Caa2 - C	Caa2 - C
Gabon	Caa1 - Caa3	Caa1 - Caa3	Caa1 - Caa3	Caa2 - C
Kazakhstan	Baa2 - Ba1	Baa2 - Ba1	Baa2 - Ba1	Ba2 - B1
Kuwait	Aa3 - A2	Aa3 - A2	Aa3 - A2	A1 - A3
Nigeria	B1 - B3	B1 - B3	B3 - Caa2	B3 - Caa2
Norway	Aaa - Aa2	Aaa - Aa2	Aa1 - Aa3	Aa1 - Aa3
Oman	Baa2 - Ba1	Baa3 - Ba2	Ba3 - B2	B3 - Caa2
Papua New Guinea	B1 - B3	B1 - B3	B3 - Caa2	B3 - Caa2
Qatar	Aa3 - A2	A1 - A3	A1 - A3	A3 - Baa2
Russia	Baa2 - Ba1	Baa2 - Ba1	Baa2 - Ba1	Baa2 - Ba1
Saudi Arabia	Aa3 - A2	A1 - A3	A3 - Baa2	Ba1 - Ba3
Trinidad & Tobago	Baa3 - Ba2	Baa2 - Ba1	Baa2 - Ba1	Baa3 - Ba2
United Arab Emirates	Aa2 - A1	Aa2 - A1	Aa2 - A1	A3 - Baa2

Source: Moody's Investor Services (2018d)

change of two or more notches from the current rating occurs due to the different demand levels and prices in this scenario.

In such a scenario, analysts need to differentiate between the relative cost base of the assets and understand the royalty and tax regime, which may offer more protection to some producers in a low-demand, low-price scenario. On the flip side, countries with significant fossil fuel import bills may reduce their exposure to imports by developing domestic renewable alternatives. In any long-term scenario, there is an opportunity for players to respond to the transition occurring, limit impacts, and potentially maximise opportunities. However, this option may be restricted if everyone is trying to do it at once, or if there are limited capacity/resources available.

Corporate risk: Sector exposure to the low-carbon transition is largely dependent on the position of or exposure to the hydrocarbon value chain. Some companies may have fossil fuels as their primary product (oil and gas producers), whilst others may be dependent on them for their business (utilities), or to use their products (transport) or supply their services (engineering contractors). On top of this, financial institutions have a portfolio exposure. This exposure is likely to be representative of the market as a whole unless financial institutions have some particular geographical or sector concentration.

In prioritising focus for assessing credit risk, it therefore makes sense to identify the sectors where transition is already occurring or expected to occur within the next few years, which ensures that efforts are directed towards sectors that require most attention. However, sector classifications cannot be perfect, and there will always be some cases that require special attention or do not fit generalisations. For example, large industrial conglomerates may sit under anonymous holding companies, which do not immediately flag up as having high-risk activities as they are diluted amongst a large portfolio of interests. A heatmap is one of such approaches to use analytical knowledge to create a framework that identifies relative exposure to this issue (Moody's Investor Services 2018b).

Table 4.3 lists the sectors that were identified by Moody's credit analysts as having high or elevated exposure to carbon regulation. The amount of rated debt (as published in September 2018) is indicated for each sector, with utilities, oil and gas companies, and transport-related companies forming the majority of the debt covered.

Table 4.3 Sectors identified as having high or elevated risk exposure to carbon regulation in the Moody's environmental heatmap in 2018

Risk category	*Sector*	*Rated debt (US$ bn)*
High risk	Unregulated utilities & power	504
	Coal mining & terminals	13
Elevated risk	Oil & gas—integrated	714
	Regulated power utilities	673
	Auto manufacturers	466
	Oil & gas—independent	470
	Surface transport & logistics	241
	US Public/Co-operative power utilities	204
	Chemicals	119
	Auto suppliers	94
	Building materials	91
	Steel	88
	Oil & gas—refining	68
	Airlines	67
	Shipping	24
	Asset-backed securities—aircraft	10

Source: Moody's Investor Services (2018b)

Each sector is different in how its carbon transition risk manifests itself. It is important to consider the objective of the analysis here. Some investors may be looking for a single metric across hundreds or thousands of corporates as a simple indicator. However, this is unlikely to provide a good measure of carbon transition risk. Carbon foot-printing is one tool that can produce this type of metric; however, it is better suited to measure the impact on the environment than the credit significance of carbon transition. There is an established methodology used to account for carbon emissions, which categorises emissions as Scope 1, 2, or 3, depending on how direct the emissions are to the entity accounting for them (WRI 2004). This methodology serves well to avoid double counting, but does not necessarily capture all relevant exposures or their financial materiality.

For example, most organisations have not historically captured the emissions that result from product use, as there is limited reporting under Scope 3 emissions. This means that for extractive companies under Scopes 1 and 2, they would only report a small fraction of the lifecycle emissions from their products, which would not reflect the significance that curtailing demand for carbon-intensive commodities might have. Recent pressure has led some hydrocarbon producers to report a broader scope of emission impacts, including the use of their products, which raises interesting questions about future liability claims. Sector-specific metrics are therefore important to ensure that main credit impacts are addressed.

The timing of the energy transition is also an important element, with some sectors more advanced or moving faster than others. The European utility sector offers an example of an industry that has undergone significant changes over a decade. It also shows how it is difficult to isolate the impact of the low-carbon transition from other factors. In this case, declining power demand, a shift away from nuclear in Germany post Fukushima, and the financial crisis all provided important context to the decarbonisation that occurred (Moody's Investor Services 2018e).

As a result of the factors identified above, the average Moody's credit rating for European utilities fell three notches over the decade to 2018, from A2 to Baa2. This is a much more gradual erosion of credit quality than seen for the US coal mining example. However, even this gradual decline has still left the sector in a poor position to finance the ongoing transition as a result of declining credit ratings. Given the importance of cost of capital for cleaner technologies, this can place incumbent utilities at a disadvantage to new participants from other sectors.

The low-carbon energy transition requires significant capital investment to deliver changes. Each sector has a typical lag time which impacts how quickly the sector can align with the transition. For example, it can take at least three years to design a new car from scratch, with extra complexity added with the adjustment to increased electrification of vehicles. In transportation, if a shipping or airline company has an existing fleet of vessels or aircraft, then it will have to consider the costs of accelerating replacement. When it comes to oil and gas, the development process for such projects can range from decades for big complex ones to months for US shale expansions. Increasing uncertainty about the status of the carbon transition at the point in the future when a new project is expected to start generating returns should impact how capital deployment risk is assessed.

Within a sector there may be significant variations or limited options for diversification. Some entities may already have decided to focus on a particular end of the green/brown spectrum. In Europe, for example, there has been significant merger and acquisition activity reorganising generation portfolios into different divisions. These business units are then clearly in different modes of operation with a clear strategy, rather than risking confusion or conflict. However, if an industry has very similar portfolios, then it may be harder to differentiate. Technological advances in one company may also be offset by geographical market advantages of another.

As with any kind of risk assessment, once the risk exposure and magnitude are established, it is usual to consider what mitigation measures may be in place. This is typical of credit analysis, which considers factors such as contractual terms, insurance, counterparties, and other measures that can alter risk associated with debt. Here, it would be salient to consider diversification into carbon-neutral or carbon-positive activities or plan to reduce portfolio exposure to carbon-intensive activities. In some sectors, it may be relevant to review investment into research and development, or the ability to pass on costs to customers.

Scenario Analysis, Sensitivity Analysis, Stress Testing

To understand how different transition scenarios may affect companies, it can be useful to apply a range of techniques to demonstrate the extent of any financial impact. Scenario analysis adjusts multiple variables to create alternative futures to help users. Scenarios are not predictions of the future; their purpose is to help users understand the potential range of outcomes. Typically, in credit analysis, this outcome is the impact on a fundamental credit ratio. Sensitivity analysis involves changing a single variable to assess the impact. For example, a range of carbon prices could be used to understand how this variable affects earnings. In addition, stress testing typically starts with a predetermined outcome in terms of a level of stress and works backwards to establish the changes required in performance to produce it. For example, a leading question might be, 'What would be required to cause a credit rating downgrade or a default?'

Moody's recently produced an analysis of the potential fines car manufacturers could receive if they fail to comply with CO_2 emissions standards for 2020–2021. This document adjusts the level of fleet emissions reductions achieved by companies, using different methods to demonstrate the penalties that would result. The combined penalties across the rated group of companies range from an estimated €2.4 billion in the rapid transition scenario, to €5.9 billion in the moderate scenario, and up to €11.2 billion if the transition is slow (Moody's Investor Services 2019a).

This kind of sensitivity analysis shows the material incentive companies have to avoid non-compliance, in this case, billions of euros for some companies. The analysis is thus not meant to be a prediction; it informs why companies are likely to take mitigation action to avoid these scenarios. For example, companies may cease production of their most polluting models, subsidise and promote low-emissions models, or pool fleets with other companies to achieve compliance. They may also choose to pay the fine if they consider it a lower cost option.

The value of these tools is that they provide a forward-looking view, rather than summarising what has already happened. Corporations are always reluctant to place too much weight on forward-looking information, which is covered by the usual legal disclaimers in annual reports. Using these insights into the future can fill some gaps in corporate disclosure and enable comparison on a consistent basis. It also gets past the challenge of trying to compare disclosures from different companies and whether they are based on the same assumptions (e.g., discount rates, commodity prices, market growth, etc.).

It is typical to apply a number of scenarios to understand the range of potential outcomes. The risk of an entity selecting their own scenario is that they choose one that is favourable to them. One example of this would be a diversified mining company asking each business unit to test performance in a low-carbon future. The coal division picks a scenario with strong carbon capture and storage deployment, the gas division picks a scenario with significant gas generation growth, the uranium division picks a scenario with high nuclear build, and the lithium division picks a scenario with rapid electric vehicle growth driving battery demand. Whilst all these scenarios may be possible in isolation, it is unlikely that planning based on the best-case scenario for each division will improve risk management or inform strategic choices. It can demonstrate potential strengthening of credit positions or the extent of potential opportunities, but it will not give insight into the potential downside.

Having reference scenarios for companies to use is therefore something financial regulators have considered, as it would also help them and the financial institutions they oversee to assess systemic risk and understand the relative levels of risk. Again, as the above mining company example indicates, there are multiple scenarios that could lead to similar outcomes in terms of overall emissions and thus global warming. Therefore, having a range of scenarios is useful to prevent biases in the analysis. In doing so, it can be possible to include reference scenarios as well as other scenarios of a company's own choosing in order to not restrict the analysis being conducted. The Institutional Investors Group on Climate Change has produced a guide to apply climate scenario analysis which explores some of these issues (Institutional Investors Group on Climate Change 2019).

Alignment with a particular scenario is hard to measure. This difficulty has been discussed in relation to the attempts to define low-carbon benchmarks or products, or to apply science-based targets (Science Based Targets Initiative 2015). These approaches tend to rely on the assumption that all entities are reflective of the overall system, and therefore the overall target that the system must meet is relevant for all entities. This assumption can certainly be used as a starting point to understand the changes needed in a sector; however, credit analysts will want to understand the context of operations for a particular operator, in terms of markets, positioning, and cost structure.

For example, Saudi Aramco recently published a bond prospectus which explains that having some of the lowest lifting costs for oil production in the world meant that they were in a stronger position to be the last producer standing than most independent producers (Saudi Aramco 2019). This view is applying an economic logic on top of the climate science to determine a market-based outcome, rather than a simpler equitable approach where the required emissions cuts are applied equally. The impact of reducing emissions will likely be greater on some parties than others. This approach mirrors the methodology applied by Carbon Tracker

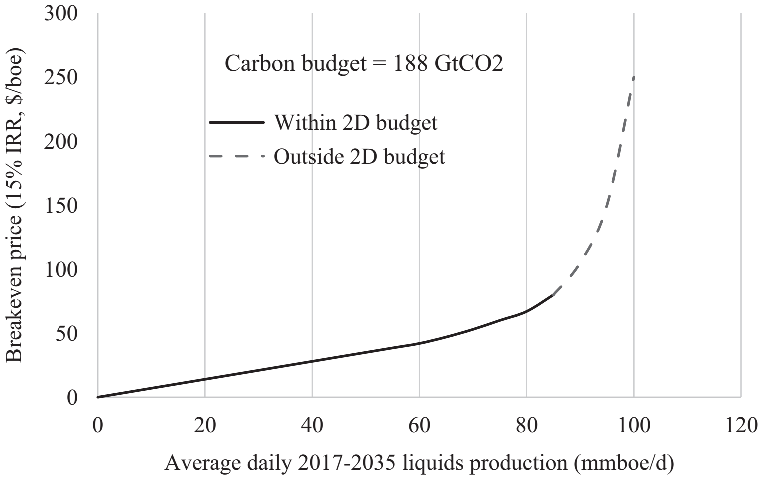

Fig. 4.2 Carbon supply cost curve for global oil supply indicating the volume consistent with a carbon budget to limit global warming to 2 °C. (Source: Carbon Tracker (2017a), modified representation)

in its carbon supply cost curves, which map out the lowest cost of coal, oil, and gas production and equate to a specific level of cumulative emissions, that is, a carbon budget (Carbon Tracker 2017a).

Figure 4.2 shows a supply cost curve for potential oil projects ranked according to breakeven cost. A cut-off is applied which shows the break-even cost for the marginal project to produce the volume of oil that would result in 188 Gt CO_2 over the period 2017–2035. This figure is based on a particular scenario with a mix of coal, oil, and gas which has a 50% change of limiting global warming to 2 °C.

Mapping Physical Risk

Changes to the earth's climate are already occurring, which means that assessments of current risk exposure need to be updated to reflect both the increasing frequency and severity of acute events, and the acceleration of chronic trends. Beyond current exposure, there is also an interest in longer-term scenarios to indicate where risks are expected to increase in the future. For example, the median risk of US commercial properties being hit by a category 4 or 5 hurricane has already risen by 137% since

1980, with modelling indicating that this will increase by 275% if no further action is taken to mitigate climate change (Blackrock & Rhodium Group 2019). The financial industry has some experience of applying historical climate data in the insurance industry to estimate potential losses from extreme weather events and develop related products. However, many of the physical risks are manifesting in developing countries, where insurance is not widespread and the data and models are not yet available.

Climate Data Applicability

Understanding the exposure to physical risks is easier for certain types of issuers than others from a credit perspective. For sovereign issuers, it is possible to apply country-level data to understand the impact on climate-sensitive sectors, which are important for the GDP, for example. In the United States, there is sufficient granularity of data to map differentials in exposure for municipal entities on some physical risk indicators (Blackrock & Rhodium Group 2019).

At the other extreme, having a complex multinational with multiple assets, businesses, and supply chains makes it harder to understand the specific locations where there is material financial exposure to physical risk, especially if data relating to either the assets or the risk exposure is unavailable.

Understanding physical risks needs to go beyond the headline numbers to the underlying data. For example, global average temperature rises are often referenced, which may not seem like large increases. Within these scenarios, however, the most extreme regional temperature increases will be multiples of the global average, having a much greater impact. Similarly, annual average increases may not tell the whole story about the number of extreme events or the period of time for which a threshold is exceeded.

Dealing with Both Events and Trends

Longer-term trends are in some ways easier to model and factor into credit analysis, as long as the speed of change is well understood. A range of outcomes can also be modelled to cover more rapid changes than the consensus or understand at what point the change has a material effect. For example, changing temperature patterns is one variable that can be modelled in this way to understand potential impacts; however, this may have to include information on changing seasonality, the number of extreme-high-/low-temperature days, and so on. The impact on relevant sectors, such as agriculture or power, can then be analysed.

The increasing frequency and severity of extreme weather events in the future can also be modelled, but it may be harder to factor into credit analysis. While it is possible to identify which region has a higher probability of a certain-strength hurricane, the model cannot tell which region will actually experience one next year. Long-term probabilities, such as 1-in-a-100-years event, do not inform short-term predictions. This unpredictability makes it difficult to integrate this type of event risk into credit analysis. Hence, the impact of hurricanes or floods on credit ratings can only be seen post event.

The Case of the California Wildfires

The increased frequency of conditions which are conducive to wildfires is increasing losses. Recent years have seen extended hot and dry seasons with delayed winter precipitation. Precipitation in the fall dampens vegetation acting as a preventative measure. If this rainfall is delayed, it leaves vegetation exposed to warmer, drier air for longer, making it more susceptible to fires. Higher average temperatures in the summer have also heightened the drying of vegetation. Additionally, heavy rainfalls in the preceding winter contribute to a greater volume of vegetation, providing more fuel for fires. If the fires coincide with strong winds, this mix can increase the scale of the damage and hamper efforts to tackle the fires (Bedsworth et al. 2018).

The hottest and driest summers have been registered in the last 20 years, including 2017 and 2018. Data from the US National Oceanic and Atmospheric Administration since 1895 shows how recent summers have seen average temperatures several degrees higher and with several inches less precipitation than average (Borunda 2018).

Table 4.4 shows the date of the 20 largest fires experienced in California in terms of structures damaged, according to the California Fire Department. This data indicates that three-quarters of the largest 20 events since records began have occurred from 2000 onwards.

However, the contribution of a changing climate is only one factor in determining the financial losses. An increasing number of structures have become exposed to wildfires as the population migrates to the wildland-urban interface (WUI). The US Department of Agriculture Forest Service reported that the number of houses in the WUI increased by 41.1% across the United States between 1990 and 2010, with some states affected more

Table 4.4 The date of the 20 largest fires recorded in California in terms of structures damaged

Fire name (cause)	*Date*	*Acres*	*Structures*	*Deaths*
1 Camp Fire *(under investigation)*	November 2018	153,336	18,804	85
2 Tubbs *(under investigation)*	October 2017	36,807	5636	22
3 Tunnel—Oakland Hills *(Rekindle)*	October 1991	1600	2900	25
4 Cedar *(human related)*	October 2003	273,246	2820	15
5 Valley *(electrical)*	September 2015	76,067	1955	4
6 Witch *(power lines)*	October 2007	197,990	1650	2
7 Woolsey *(under investigation)*	November 2018	96,949	1643	3
8 Carr *(human related)*	July 2018	229,651	1604	8
9 Nuns *(under investigation)*	October 2017	54,382	1355	3
10 Thomas *(under investigation)*	December 2017	281,893	1063	2
11 Old *(human related)*	October 2003	91,281	1003	6
12 Jones *(undetermined)*	October 1999	26,200	954	1
13 Butte *(power lines)*	September 2015	70,868	921	2
14 Atlas *(under investigation)*	October 2017	51,624	783	6
15 Paint *(arson)*	June 1990	4900	641	1
16 Fountain *(arson)*	August 1992	63,960	636	0
17 Sayre *(misc.)*	November 2008	11,262	604	0
18 City of Berkeley *(power lines)*	September 1923	130	584	0
19 Harris *(under investigation)*	October 2007	90,440	548	8
20 Redwood Valley *(under investigation)*	October 2017	36,523	546	9

Source: California Fire Department

than others (Martinuzzi et al. 2015). This trend increases the value of the assets at risk and any potential insurance or liability claims. The entities which bear the financial liability, are then determined by the legal regime in place in that location and the circumstances of the fire. In California, the application of inverse condemnation to utilities, even where no negligence was found, meant it was the utilities who were the de facto insurer for fires in 2017 and 2018. As a result, the Californian utility PG&E filed for bankruptcy protection in January 2019 due to the scale of wildfire liabilities it had to cover.

Physical Risk Mitigation

In determining the impact on credit strength, analysts consider several mitigating factors, such as investment in adaptation, insurance, expected bailouts, and potential liabilities. After reviewing the impact on US cities a year after major floods or hurricanes, one can see that it is possible for a city to be in a better position than before the event (Moody's Investor Services 2018c). This could be a result of a combination of factors: federal bailouts, investments in new infrastructure, improved resilience and response plans, and insurance pay-outs. It could therefore be argued that US locations that have already experienced an extreme weather event are better placed going forward than those that have not.

The financial impact is therefore transferred elsewhere and is more manageable if it is being diluted amongst much larger federal budgets and insurance portfolios. In countries without funding for federal agencies or widespread insurance cover, cities and regions take much longer to recover, and local economies may suffer for prolonged periods as a result. Analysts need to trace where the financial liability falls. At present, some governments, such as the US federal administration, have a history of bailing out local governments when events occur. There is some debate as to whether this will continue indefinitely if losses keep increasing. Some US cities are already using 'resilience bonds' to use the capital markets to secure funding for improving infrastructure. For example, San Francisco and Washington DC have issued 'green bonds' to fund stormwater management infrastructure, and Harris County, Texas issued a 'flood bond' to finance flood prevention works after experiencing Hurricane Harvey in 2017.

Some locations are also investing in adaptation measures, which will reduce exposure to losses in the future. For example, cities such as Cape Town are already suffering water shortages due to the increased frequency of drought events. This situation resulted in economic losses due to reduced agricultural outputs, lower water revenues, and lost tourism income, as well as further knock-on effects on financial institutions and the wider economy (UBS 2018). At the same time, the city had to increase expenditure to improve the water infrastructure. This combination was credit-negative for the city for a period of time.

Following the shortages, local administrations have initiated programmes to improve water management, reduce consumption, and augment supply, which are reflected in the vulnerability assessment of Cape Town. This case shows that when a water shortage occurs, there is a visible incentive to invest in solutions. However, these solutions may come too late to minimise losses. There is still a major shortfall in investment in climate resilient infrastructure elsewhere; however, analysts are starting to recognise the benefits of reduced vulnerability in their credit assessments, which helps justify expenditure.

Conclusion

Integrating climate risk into credit analysis is an evolving field, with the tools and data required still being developed and refined. Physical and transition climate risks are increasingly material for creditworthiness, with scenario and sensitivity analyses useful approaches to understand potential future exposure. The ability of entities to transfer risk or pass on costs makes it essential to have a system view that can understand where impacts may ultimately land across the capital markets.

Event risk will continue to present a challenge, even with better analytical tools, as no one can predict in advance exactly where and when extreme weather events will occur. Trends in terms of changing energy technologies and climatic conditions are easier to identify. For these trends, the challenge lies in assessing whether the individuals running companies or governments are making the necessary adjustments, or just betting on the status quo. The experimental nature of the approaches being applied to examine the credit impacts of climate risk confirms that this field is still at an early stage.

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