PGIM

MEGATRENDS

WEATHERING CLIMATE CHANGE

Opportunities and risks in an altered investment landscape

SPRING 2021

FOREWORD

After 100 centuries of relative stability, our planet's climate is transforming.[1] This climatic change is not a distant forecast of the future – it is verifiably happening now. Indeed, despite the significant uncertainty over the longer horizon, our climate destiny is largely predetermined over the next two decades – beyond the typical time frame of most long-term investors.

Ironically, a highly certain climate destiny translates into massive uncertainty for long-term investors looking to navigate the opportunities and challenges unleashed by climate change. This is for a variety of reasons. First, the most definitive forecast of climate change is for more extreme and greater variability in weather outcomes, the precise timing and severity of which are unclear. Second, it is hard to predict when the externalities, tail risks and nonlinear vulnerabilities from climate change will be fully reflected in market prices. Third, the regulatory, governmental and societal response to climate change remains unclear, especially given the polarized political landscape in which climate change discussions are currently being conducted.

Despite these uncertainties, we believe that climate change is one of the most important structural changes for long-term investors. The implications for investors lie as much around innovative and transformative technologies to further the transition to a lower-carbon world as they do around identifying and mitigating hidden vulnerabilities across their portfolio.

To build an actionable climate change investment agenda, we have drawn on the insights of over 45 investment professionals across PGIM's fixed income, equity, real estate, and private debt and alternatives managers; interviewed over 30 leading academics, economists, policymakers, scientists and climate change investors; and conducted a new proprietary survey of over 100 global institutional investors to better understand their current investment actions and future aspirations around climate change.[2]

The humanitarian and economic catastrophe unleashed by COVID-19 in 2020 revealed investors' vulnerability to nonlinear risks with unpredictable timing that are not easily accounted for in standard risk modeling. Climate change is the next slow-burning crisis that will radically reshape investors' risks and opportunities over the next decade. Here at PGIM, we believe investors who understand the potential for climate change to disrupt and reshape the global economy, markets and the investment landscape will be best positioned to navigate the coming decades.

David Hunt
President and Chief Executive Officer
PGIM

Taimur Hyat
Chief Operating Officer
PGIM

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Chapter One summarizes the compelling evidence that climate change is not a distant tail risk but a stark reality. The frequency and magnitude of destructive weather events has increased markedly – and will continue to do so for the coming decades. All investors, whether they have an environmental, social and governance (ESG) focus or otherwise, will need to navigate the shifting macroeconomic, market and investment landscape that lies ahead.

CHAPTER 2
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Chapter Two examines the macro implications of the multi-decade transformation that is underway from a fossil fuel-based economy to a low-carbon economy. We provide PGIM's perspective on regions and sectors that will be most vulnerable to the ongoing climate change transition.

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Chapter Three examines how (and if) markets are pricing transition and physical risks from climate change. We explain why markets have priced these risks so inconsistently and identify some catalysts that may trigger a broader repricing of climate risks across different asset classes in the future.

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Chapter Five discusses the portfolio-wide implications of climate change, including the challenges of assessing and modeling climate risk across a multi-asset portfolio. We propose a portfolio-wide climate action plan for institutional investors.

CHAPTER 1

CLIMATE CHANGE IS TODAY'S REALITY

> *Though policymakers, businesses, and activists may disagree on many aspects of climate change, there is one indisputable fact: the air and water on our planet are warming – and this global warming is accelerating.*

CHAPTER 1

CLIMATE CHANGE IS TODAY'S REALITY

Climate change is no longer a hypothetical risk. Though policymakers, businesses, and activists may disagree on many aspects of climate change, there is one indisputable fact: the air and water on our planet are warming – and this global warming is accelerating (Exhibit 1).

Disruptive climate change is already underway

One of the most tangible effects of climate change is already well underway – the surge in extreme weather. If there was a VIX for weather, it would be near all-time highs – and trending higher still. Exhibit 2 illustrates this greater weather volatility in rainfall patterns. That is because warmer air and sea temperatures are catalysts for increasingly volatile weather, spurring both extreme heat and cold in some areas and drought and floods in others.

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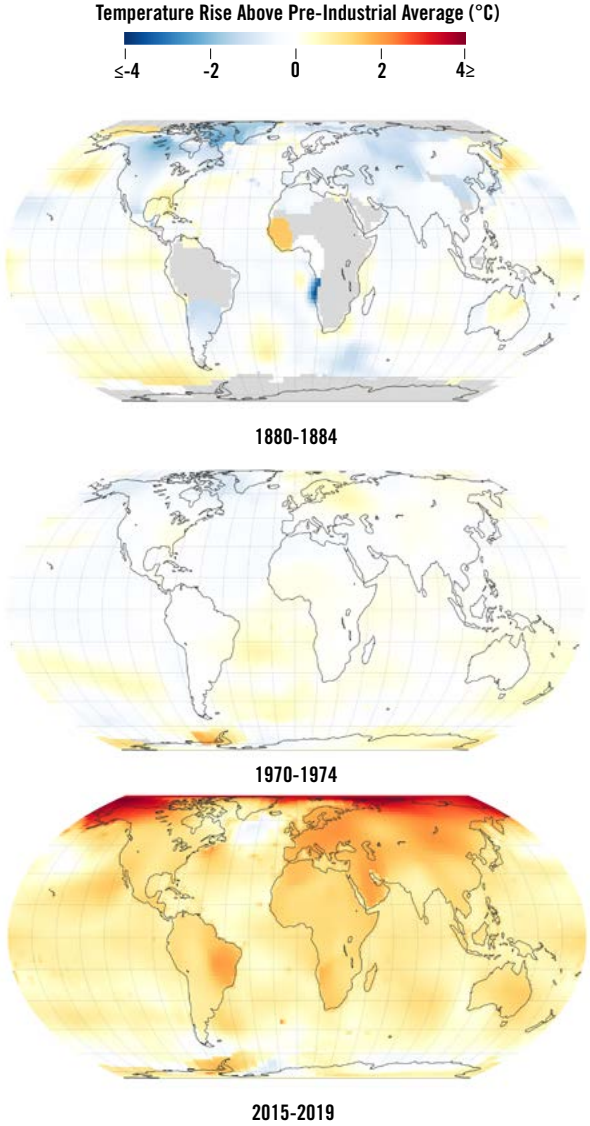
Extreme temperatures

Climate change has led to a rise in extreme heat waves.[i] In India, one of the countries hit hardest, the number of officially recorded heat waves reached 484 in 2018, more than 10 times the number during the entire decade of the 1970s (Exhibit 3).[3] Similarly, Africa experienced 24 extreme heat waves annually in the period between 2006 and 2015 – double the pace for the 25-year period preceding it.[4] Even in the Siberian Arctic, a heat wave in June 2020 saw summer temperatures break 100° F (38° C) for the first time in recorded history.[5]

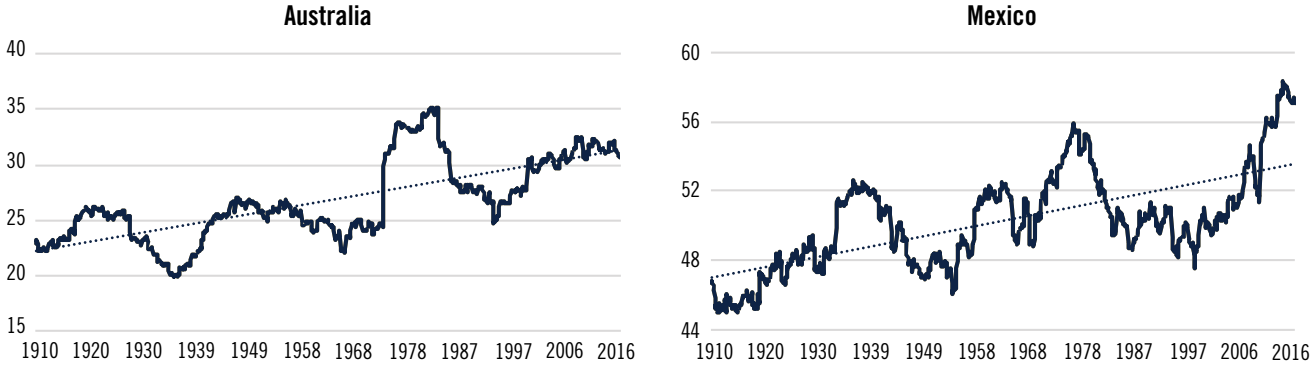
Exhibit 1: **Global Mean Temperature Has Been Rising Since 1880**



Source: "World of Change: Global Temperatures," Earth Observatory, NASA, accessed 2020.

i The rise in global urbanization has also exacerbated the impact of rising temperatures and episodes of extreme heat. For more information on urbanization, see "The Wealth of Cities" http://www.wealthofcities.com

Exhibit 2: **Too Much and Too Little: Rising Variability in Rainfall**
10-Year Rolling Standard Deviation of Monthly Rainfall (mm)



Source: PGIM analysis; "Climate Change Knowledge Portal," World Bank, accessed 2020.

Somewhat counterintuitively, the warming of the planet also leads to extreme cold spells – particularly across North America, Europe and Central Asia.[6] When there is a sharp contrast between icy arctic temperatures and the rest of the world, the jet stream flows strongly along a predictable west-to-east latitudinal path that traps the polar air in the Arctic. But, as Arctic air temperatures increase, the decline in the temperature differential weakens the jet stream and allows it to meander southward. This brings frigid Arctic air (the polar vortex) to lower latitudes across North America, Northern Europe and Central Asia.[7] One episode in 2019 saw temperatures in Chicago and Minneapolis drop to -46°C (-50°F), causing major disruptions in transportion and other infrastructure.[8]

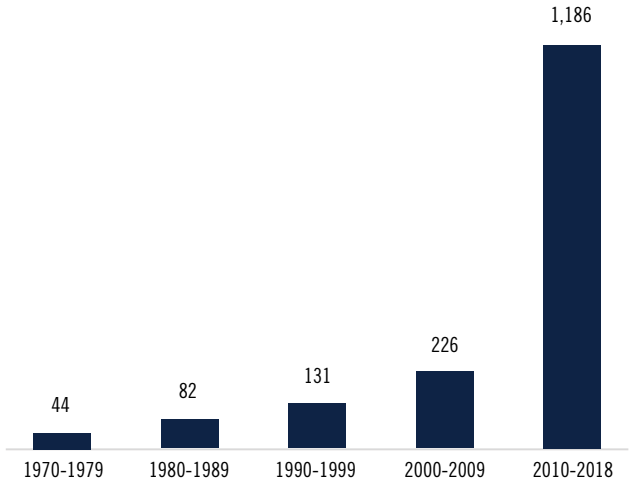
Growing intensity of storms and hurricanes

There is growing evidence global warming is leading to an increase in storm severity. Warming oceans have created higher-intensity hurricanes in the North Atlantic and cyclones in the South Indian oceans, leading to more storms achieving category 3 or higher intensity (Exhibit 4).[9] Indeed, the number of named storms in the Atlantic hit a new record in 2020.[10]

In addition to hurricanes, warming air raises the atmospheric water retention rate which increases the frequency of severe rainfall events.[ii] Estimates suggest that the atmosphere's capacity to hold water vapor goes up by 7% for each degree C of warming.[11] While this process has been occurring globally, it has impacted rainfall patterns most severely in Europe, Japan and the US.[12]

For example, in the US the heaviest daily rainfall each year has increased since 1950 in almost 80% of the 244 cities analyzed.[13] There has been a similar trend in Western Europe, where the average spring rainfall has risen since at least the late 20th century (Exhibit 5).

Exhibit 3: **Total Officially Recorded Heat Waves in India by Decade, 2010-2018**



Source: "Extreme Events and Disasters," India Meteorological Department, Ministry of Earth Sciences, 2019.

[ii] Defined as days where precipitation falls within the top one percentile of average precipitation for the specified time period.

Desertification, drought and wildfires

With rising weather variability and changes in rainfall patterns, some parts of the world are becoming markedly more arid. Southern Europe provides a compelling example. It is relatively common to hear warnings of the Sahara Desert creeping northwards and even jumping the Mediterranean Sea.[14] In reality, this process is well underway. Warming temperatures and variations in rainfall patterns have already led to growing desertification in parts of Portugal, Spain, Greece and Italy, with the change visible even over the last 10 years.[iii] As recently as 2019, hot desert air from the Sahara reached France, generating temperatures of nearly 46°C (115°F).[15]

Increasing aridity has in turn led to more frequent and severe wildfires and droughts with a growing proportion of global vegetation exposed to ever-longer wildfire seasons.[16] Indeed, the 2019-2020 wildfires in Australia, Europe and the United States have been some of the most intense and damaging wildfires in recorded history.

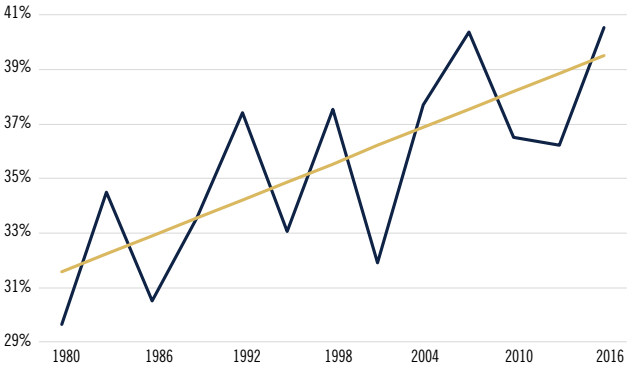
As for droughts, the eastern Mediterranean region – Cyprus, Israel, Lebanon and Turkey – has been in a near continuous drought since 1998 with 50% less groundwater than the driest period in the past 500 years.[17] In the past decade, California also had its worst drought in over 1,200 years.[18]

Flooding

Perhaps the most visible impact of climate change has been the increase in flooding – both coastal and inland. Hotter temperatures and melting polar ice

Exhibit 4: **Storms Are Getting More Intense**

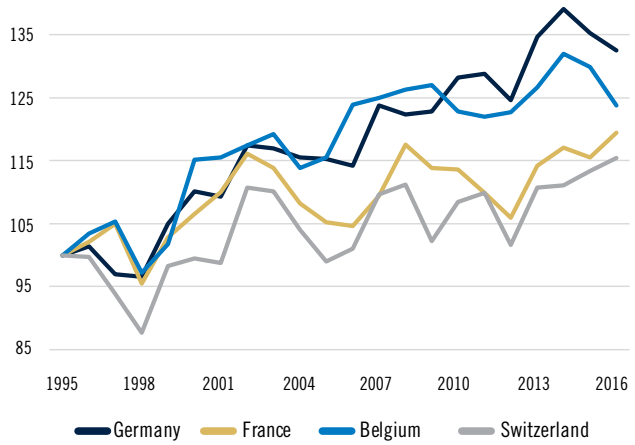
Proportion of Global Major Hurricanes (Category 3-5) to Total Hurricanes, 1979-2017



Source: James P. Kossin, et al., "Global increase in major tropical cyclone exceedance probability over the past four decades," Proceedings of the National Academy of Sciences of the US, May 18, 2020
Note: Points represent three-year averages

Exhibit 5: **Average Rainfall Has Been Increasing Across Many European Countries**

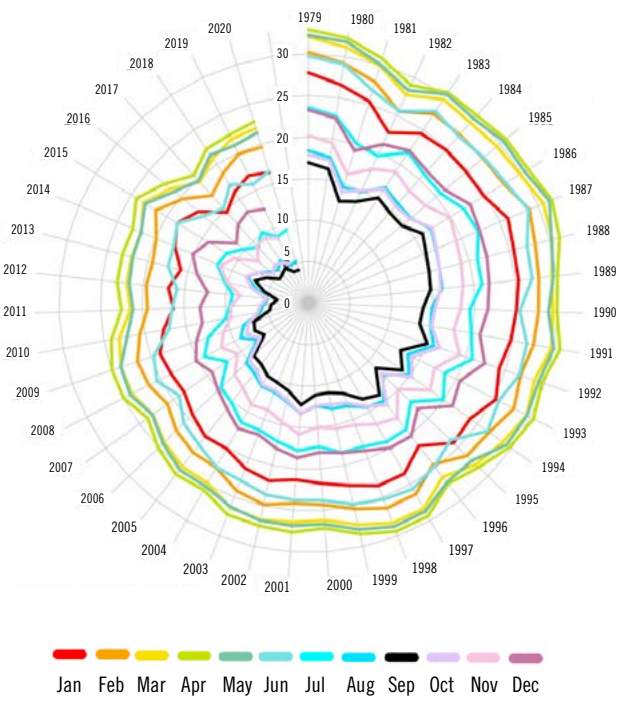
10-Year Rolling Average Rainfall in May (Indexed to 1995)



Source: PGIM analysis; "Climate Change Knowledge Portal," World Bank, accessed 2020

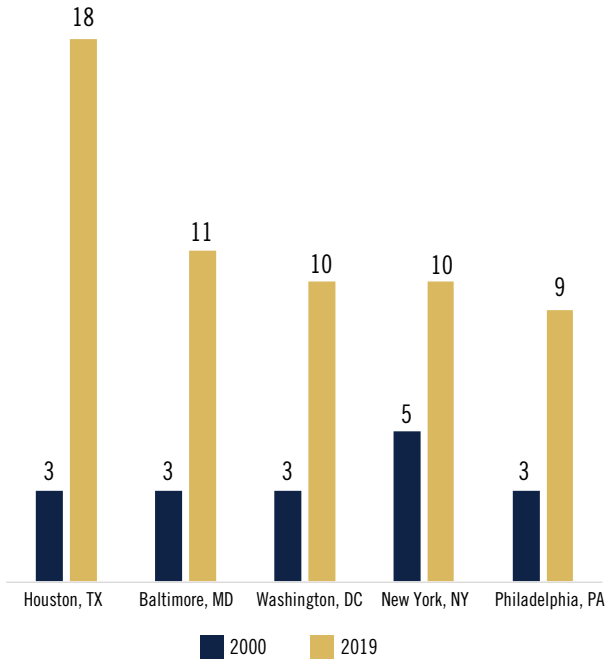
[iii] Desertification is generally defined by six dimensions: water erosion, wind erosion, vegetation degradation/loss, salinization, soil compaction, and soil fertility decline.

Exhibit 6: **Arctic Sea Ice Is Receding**
Sea Ice Volume (1,000 km³)



Source: Ben Horton, "Arctic Death Spiral," accessed 2020

Exhibit 7: **More Frequent "Sunny Day Floods" in Major US Cities**



Source: "The State of High Tide Flooding and Annual Outlook," US National Oceanic and Atmospheric Administration, 2020

caps directly contribute to the rise in average sea level, which accelerated in recent decades (Exhibit 6). According to NASA, the global sea level at the end of 2019 was the highest in recorded history – 3.8 inches above the 1993 average.[19]

As a result, coastal ocean flooding has risen dramatically. This not only means stronger storm surges and rising saltwater contaminating groundwater, but also more frequent flooding at high tide even without severe rain events. These so called "sunny day floods" have become more frequent across many major metropolitan areas in the US since 2000 (Exhibit 7). In Southeast Asia, Jakarta, Manila, Bangkok, Ho Chi Minh City and Hanoi are also experiencing tidal flooding at an increasing rate. This is part of the rationale for Indonesia relocating its capital away from Jakarta.[20]

> *The next two decades of climate change have already been largely determined.*

Flooding is not limited to coastal regions either. More intense and frequent downpours have led to an increased incidence of flooding episodes further inland as well. River floods have become more common in Northwestern and Central Europe, caused by increasing autumn and winter rainfall.[21] An extreme occurrence in 2013 culminated in widespread flooding in Germany, Austria, Slovakia and the Czech Republic.[22] More rapid glacial melts can also contribute to river flooding, especially in the Himalayas.[23] In the US, a significant increase in the number of heavy precipitation days across the Midwest has contributed to massive flood events due to swelling rivers.[24] 2019 was a particularly difficult year for the Midwest and South when the Mississippi River crested.[25]

The planet's transformation will continue under all plausible scenarios

The next two decades of climate change have already been largely determined. Irrespective of the near-term forecast for carbon pricing or renewable energy, there is little variation and uncertainty in the trajectory of climate change for the next 20 years. That is because today's climate change is the result of greenhouse gases (GHG) emitted decades ago. Likewise, today's actions around GHG emissions will only alter climate outcomes decades from now.[26]

For example, the annual probability of a severe drought in China increases by roughly the same amount through 2040 under either rosy or gloomy climate scenarios. Similarly, Brazil will experience a significant increase in the number of dangerous heat days under either scenario.

Perhaps even more telling, these changes under the most optimistic scenario (RCP 2.6) remain significant through 2040, implying that even if the world were to drastically cut its emissions today, the impacts of climate change will still be felt over the investment horizon of most institutional investors (Box 1).

Box 1: **Representative Concentration Pathways**

In the scientific community, the most cited climate scenarios are the Representative Concentration Pathways (RCPs), developed in 2010 and adopted by the United Nations' Intergovernmental Panel on Climate Change (IPCC). Four key scenarios are defined as (1) very low emissions (RCP 2.6), (2) medium-low emissions (RCP 4.5), (3) medium-high emissions (RCP 6.0), and (4) high emissions (RCP 8.5) (Exhibit 8). The RCPs provide a useful framework to understand how climate change may impact the economy, policy and the environment. The various scenarios account for a range of complex interactions between environmental, political, and economic systems. These pathways continue to evolve as our planet transforms and our understanding of climate change progresses.

There are clear differences between climate scenarios, especially between the most optimistic (RCP 2.6) and the most pessimistic scenario (RCP 8.5). However, even these extreme projections have a very similar path of climate change for the next two decades. That is, the bookend 2.6 and 8.5 scenarios only begin to diverge after roughly 20 years. Of course, from a 100-year perspective the planet could follow a range of outcomes, with major societal implications, but in many ways our climate destiny through 2040 is already determined.

Name	Temperature Rise by 2100 (°C)	Description of Scenario
RCP 2.6 (Most Optimistic)	1.5	There is stringent mitigation with a peak and decline of greenhouse gas emissions starting around 2020. CO_2 concentrations peak around 2050, followed by a modest decline by the end of the century.
RCP 4.5	2.4	Overall greenhouse gas emissions remain relatively flat through 2100, except for CO_2 emissions, which begin to decline by around 2050. CO_2 concentrations grow until around 2075 and then begin to level off.
RCP 6.0	3.0	Overall greenhouse gas emissions remain relatively flat through 2100, with CO_2 emissions peaking around 2060 and then declining slightly to level off by 2100. CO_2 concentrations continue to rise through 2100.
RCP 8.5 (Most Pessimistic)	4.9	Greenhouse gas emissions rise exponentially through around 2070 and then grow at a slower rate through 2100. CO_2 concentrations rise exponentially through 2100.

Heightened risk of tipping points and feedback loops

There is increasing evidence the world is reaching tipping points in climate change that will have lasting, irreversible impacts.[27] These tipping points could create a cascading chain of events that accelerate climate change even further. In fact, a major reason for initial calls to limit warming to 2 degrees Celsius was research showing the risk of tipping points goes up exponentially around that level. However, a recent study in *Nature* suggests such tipping points could be triggered with even moderate warming, far lower than previous predictions.[28] With the global average temperature already rising about 1°C, some tipping points may already have been reached. No amount of reduction in greenhouse emissions today could alter that course for the next few decades.

The prevalence of feedback loops in the global climate system make adverse environmental impacts exceedingly difficult to control and limit. For example, about 30% of the energy reaching Earth from the sun is reflected back into space. As a highly reflective surface, ice plays a major role in this. Therefore, as the polar ice caps melt, less of the sun's energy gets reflected back into space and instead is absorbed by land and water – leading to more ice melt. Similarly, as the Arctic permafrost melts, more carbon dioxide and methane that have been trapped in it for centuries get released into the atmosphere, accelerating the very warming that melted the permafrost in the first place.

The critical takeaway for investors is clear: even under the most benign scenarios, our planet and climate will continue to change rapidly. Regardless of whether investors tilt towards ESG objectives, the sweeping impact of climate change across geographies and industries cannot be ignored. This creates both new opportunities and risks for investors' portfolios, which we explore over the next four chapters at the macroeconomic, market, asset class and cross-portfolio levels.

CHAPTER 2

CLIMATE IS A MAJOR MACRO FACTOR

> *There is a well-established, empirically grounded body of research on the transmission mechanisms from climate change to lower economic growth via labor productivity, agricultural yields, and fiscal spending.*

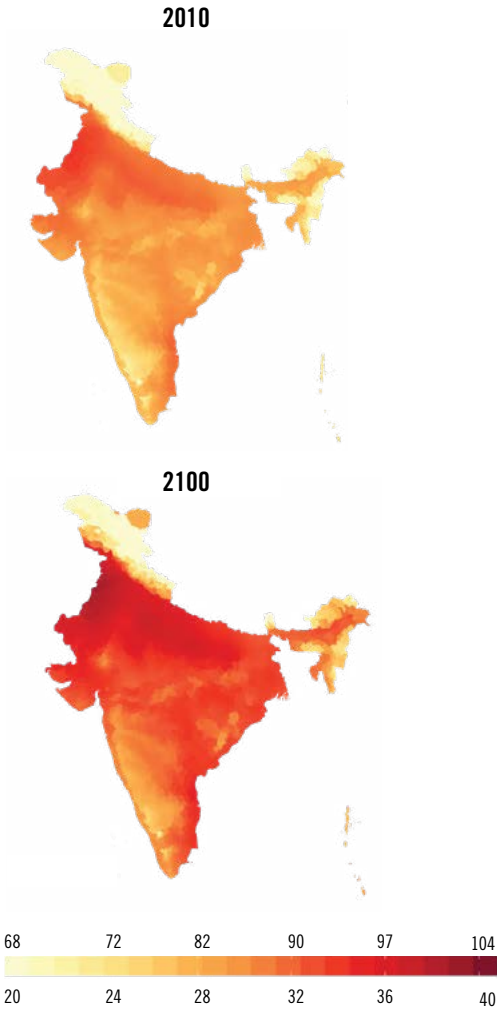
CHAPTER 2
CLIMATE IS A MAJOR MACRO FACTOR

Climate change is not only altering the contours of our planet and weather system, it is also transforming the global economy. This metamorphosis will spur a generational reallocation of resources over coming decades – leading to the emergence of a new set of winning and losing countries and sectors.[29]

There is a well-established, empirically grounded body of research on the transmission mechanisms from climate change to lower economic growth via labor productivity, agricultural yields, and fiscal spending (Table 1). In this chapter we focus on three critical implications of this for investors:

- **A highly uneven impact across countries and sectors.** The impact of climate change on growth will be unevenly spread across countries, with many emerging markets such as India bearing the brunt of the consequences while a few developed countries close to the poles remaining mostly untouched (Exhibit 8). There will be a wide dispersion across sectors in the economy as well.
- **A prolonged sunset for fossil fuels.** The evolution from a global economic system marked by virtually unconstrained use of inexpensive fossil fuels to one that fully prices in the externalities of greenhouse gases will be the defining transition of our generation – but will play out over a significantly longer time horizon than many investors might be expecting.
- **The indirect, knock-on effects from climate change are likely to be more consequential than the direct ones.** The socially and politically disruptive second-order effects of climate change – escalating risks like "climigration," civil and political unrest due to water scarcity, widespread zoonotic diseases – could ultimately overwhelm first-order effects.

Exhibit 8: **Heat Risk in India Is Rising**



Source: "Climate Change and Heat-Induced Mortality in India," Climate Impact Lab, 2019
Note: Average daily summer temperatures calculated over June, July, and August. This exhibit shows the rise in temperature under the RCP 8.5 scenario.

Table 1: **Macroeconomic Implications of Climate Change**

	Labor Productivity	Agriculture Yields	Government Deficits
Key drivers	■ Disruptions to transportation and electrical systems due to extreme weather events ■ Physical and cognitive decline due to rising temperatures outdoors and indoors ■ Increased absenteeism due to higher morbidity rates	■ Deviations from longstanding patterns of temperature and rain ■ Rising salination of farmland from sea level rise ■ Extreme heat stresses both livestock and crops ■ New weather conditions bring new weeds, insects, vermin and crop disease to previously unexposed areas	■ Rising costs for essential adaptation and mitigation projects ■ Reduced revenues from decreased economic production ■ More frequent emergency spending for disaster recovery
Potential magnitude	■ **Up to 2% of global GDP annually:** Current estimates suggest the annual productivity loss from global warming amounts to roughly 2% of global GDP[30]	■ **6-14% annually:** A 2 degree-Celsius increase in global temperature reduces global yields of agricultural staples such as wheat, maize and rice by 6-14% in the absence of technology or mitigation efforts[31]	■ **$100s of billions:** In 2017, for example, multiple major hurricanes hit the US leading to hundreds of billions of emergency federal spending that year alone
Where will the impact be felt most?	■ Sectors: Construction, mining, manufacturing, agriculture ■ Equatorial countries highly impacted (e.g., Brazil, Nigeria and India) ■ Northern polar regions least impacted (e.g., Canada, Scandinavia, Russia)	■ Equatorial countries highly impacted (e.g., Pakistan, Iran and Nigeria) ■ Coastal countries highly impacted (e.g., Australia, Vietnam and India) ■ Crop yields may increase in northern Europe, Russia and Canada	■ Municipal and state government finances will be most vulnerable ■ Sovereign fiscal budgets may be strained as private property losses are nationalized under emergency measures

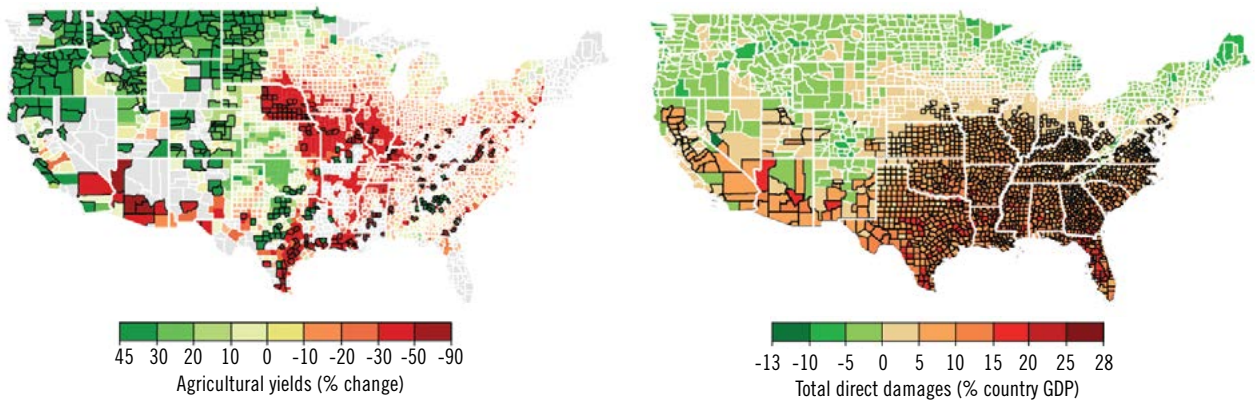
1. Climate change's impact on productivity and economic growth will be highly uneven

Climate change has already begun to cause a wide range of physical effects. Rising sea levels, more intense droughts, floods and storms, changing weather patterns, waves of extreme heat all pose serious challenges for firms, investors and the broad economy. Collectively, these are often referred to as physical risks from climate change.

These physical risks will curtail growth around the world. However, growth in developed markets is likely to be less impaired than emerging markets. According to the International Monetary Fund (IMF), the median effect of a 1 degree Celsius annual increase in average temperature on annual GDP per capita growth is minimal for advanced economies, which tend to have colder climates on average. At an extreme, remote parts of Russia may see an economic boom as previously uninhabitable polar regions become more hospitable to farming and other economic activity.

However, there will be significant variation in climate effects *within* individual countries. The US is a good example (Exhibit 9). Areas along the Atlantic Ocean and Gulf of Mexico are impacted by rising sea levels and more frequent, damaging hurricanes. The southwestern US will experience extreme heat,

Exhibit 9: **Climate Change Will Have a Varied Impact Across the United States**



Source: Solomon Hsiang, et al., "Estimating Economic Damage from Climate Change in the United States," *Science*, June 30, 2017

drought, and wildfires. Meanwhile vast stretches of the northern sections along the border with Canada will hardly be impacted at all.

Second, the economic effects of climate change will also be more severe in emerging markets. Many equatorial climates – namely, emerging markets in South America, Asia and Africa – have higher average temperatures and are more likely to see significant declines in productivity and growth due to climate change. Over the long term, this may shift aspects of economic production away from the equator. And while these adversely impacted economies generate two-fifths of global GDP today, they account for 85% of the current population.[32] Furthermore, many have large agriculture sectors which will be increasingly vulnerable. The heightened impact of climate on emerging markets may also accelerate political instability and inter-regional wealth inequality.[33] Even among emerging markets, the impacts of climate change will be uneven and disparate. Within the MSCI EM Index, for example, there is a wide dispersion of climate impact among its constituents (Exhibit 10).

Third, the impact across sectors of the economy will be broad as well. While virtually all sectors will feel the impact of climate change, some will be adversely impacted more than others. For example, airlines, utilities and energy are highly vulnerable to transition risk given their reliance on high-carbon fossil fuels. Many segments of the food complex – including soft drink and beer producers, fisheries and wineries – face future challenges from physical risk. Additionally, construction and some areas within the hotel and entertainment sectors are vulnerable to physical climate risk.

It may be intuitive for investors to merely avoid those sectors most vulnerable to climate change. However, such an approach may overlook significant

Exhibit 10: **There Is Wide Divergence in Climate Risk Across Emerging Market Countries**

Climate Risk	MSCI Emerging Market Index		JP Morgan Global Bond Index – Emerging Markets	
Low	South Korea Czech Republic Poland	United Arab Emirates Chile	Czech Republic Poland Russia	Malaysia Hungary
High	South Africa Brazil Indonesia	Philippines India	Turkey Mexico Peru	South Africa Brazil

Source: Notre Dame Global Adaptation Initiative Country Index, data released July 2020

opportunities, given there is extensive variation within each sector as well. As we explore in Chapter 4, active investors may find some pockets of outperformance even within the most vulnerable sectors.

2. A prolonged sunset for fossil fuels

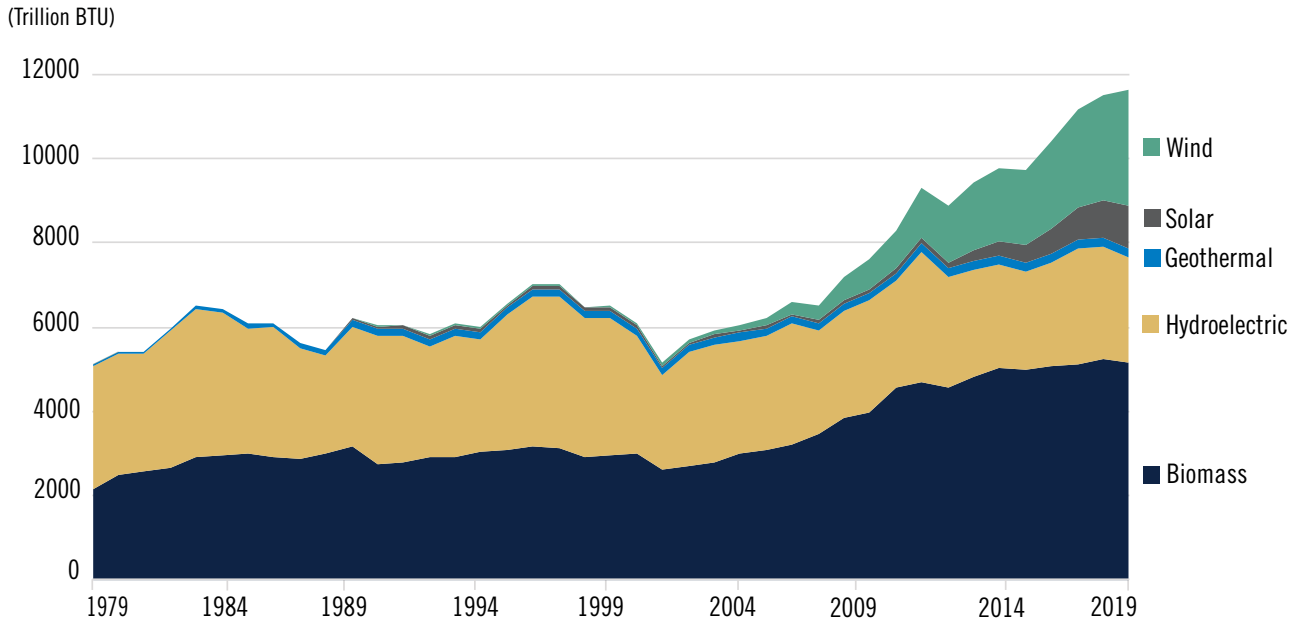
The transition to a low-carbon economy is already underway, creating the threat of stranded carbon assets. This is often referred to as transition risk. This is apparent in both the relative shrinking of the oil and gas sector in global markets and the coincident rapid expansion of renewable energy.

Take the market value of Exxon Mobil, for example. Just seven years ago, Exxon had the largest market capitalization of any US company. Since then it has lost more than half of its value – in part reflecting more transition risk – and finally being removed from the Dow Jones industrial average in August 2020.[34] In late 2020, NextEra, the world's largest provider of wind and solar energy, actually surpassed Exxon Mobil in market valuation.[35] Indeed, the energy sector has fallen from the S&P 500's second largest sector by weight in 2008 to its smallest today.[36]

At the same time, 2019 was the first year solar and wind made up the majority of the world's new electrical power generation – a seismic shift in how nations get their electricity. In 2010, wind and solar made up less than a quarter of new power generation. Now, they account for more than two-thirds.[37] In the US, renewable energy capacity has nearly doubled since 2000, and now accounts for almost 20% of utility-scale electricity generation (Exhibit 11).[38]

However, there is a long way to go before arriving at a new, low-carbon economy. Fossil fuels (e.g., coal, oil, LNG and natural gas) account for nearly 80% of global energy consumption today. Under current policies, consumption of renewable energy is forecast to double over the next 20 years. However, fossil fuels are projected to still account for about 70% of global energy consumed in 2050 (Exhibit 12).[39]

Exhibit 11: **U.S. Electricity Generation From Renewables Has Expanded Rapidly Since 2000**

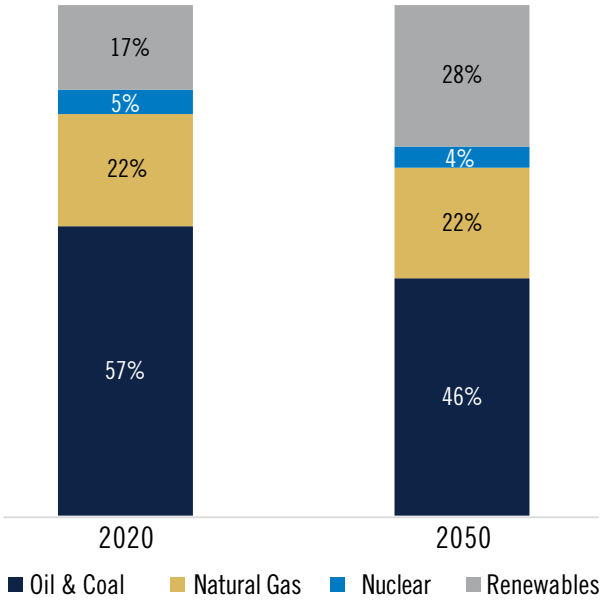


Source: "October 2020 Monthly Energy Outlook," US Energy Information Administration, October 2020

The truth is that renewable energy faces significant challenges today. First, to decarbonize the world's power generation, energy storage capacity needs to grow tremendously. The most scalable renewable energy sources such as solar and wind are intermittent, meaning they cannot provide a constant source of energy. As a result, utility companies must maintain some fossil fuel capacity – which can be switched on and off easily – to meet peak energy demand on days when the sun and wind are not strong. Of course, battery storage and transmission can ease renewable energy's intermittency problem. But the technology is not sufficiently scalable yet and material improvements around cost and storage efficiency are still needed.

Second, to build out renewable energy capacity and infrastructure to a sufficient scale – from transmission networks for wind and solar to electric charging stations along highways – requires a massive amount of investment and time. According to one recent estimate, it would take $120 trillion in cumulative investment between 2015 and 2050 to reach the Paris Agreement goal of limiting global temperature rise below 2 degrees Celsius.[40] This would amount to more than $3 trillion of global investment every year until 2050. Though some of this investment would still be allocated to fossil fuels and energy efficiency, more than half would need to go towards renewables and electrification of transport and infrastructure.

Exhibit 12: **Share of Global Energy Consumption by Source, 2020-2050**



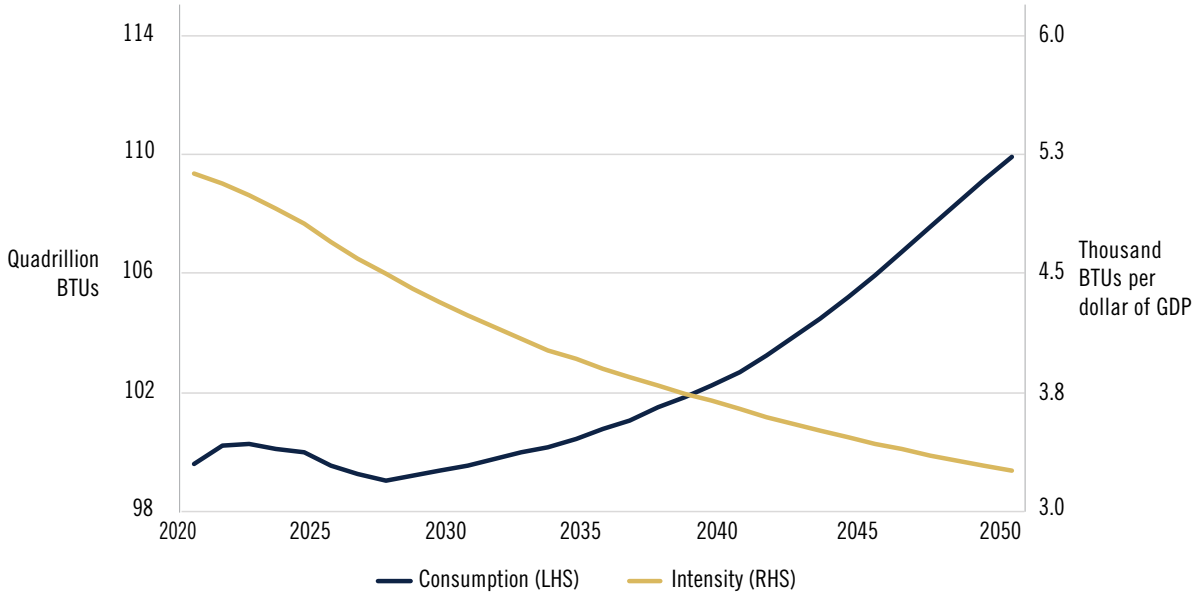
Source: "Annual Energy Outlook 2020," US Energy Information Administration, January 2020
Note: Totals might not add to 100% due to rounding

> *Fossil fuels will remain a prominent feature of the global energy landscape for decades.*

Third, and perhaps the greatest challenge, is that even as the transition away from fossil fuels progresses, the end goal is moving further away. Global energy demand is forecast to grow by nearly 50% between now and 2050, according to the US Energy Information Agency (EIA). This is driven mainly by emerging markets, for whom improving energy access is essential to lift millions out of poverty and develop their economies. In sub-Saharan Africa, only 50% of the population has access to electricity.[41] Meanwhile, China consumes just 35% of the electricity the US consumes per capita.[42] This indicates significant room for growth in electricity consumption in these regions. Energy efficiency measures can slow this demand growth, but will not reverse it. This is evident in the US, where energy consumption will continue to grow even as energy intensity (the amount of energy consumed per dollar of GDP) declines dramatically (Exhibit 13).

Given that fossil fuels remain abundant, easily transportable and can be switched on and off, they will remain a prominent feature of the global energy supply for decades to come. We shall return to this theme in Chapter 5, when we explore opportunities at the greener end of brown industries.

Exhibit 13: **U.S. Energy Consumption Will Increase While Intensity Will Decrease**
Energy Use and Intensity Forecast, 2020-2050



Source: US Energy Information Administration, data accessed 2020
Note: British thermal units (BTUs) are used to measure thermal heat, or energy

3. Indirect effects from climate change could be very significant

The US Department of Defense has cited climate change and a myriad of second order effects – food and water scarcity, zoonotic diseases, climate-induced migration – as "threat multipliers."[43] This will exacerbate existing social and political tensions such as poverty and inequality and even spark new geopolitical conflicts. These knock-on effects from climate-driven stresses are likely under-weighted on investors' agendas.

Internal displacement and migration

Between 2008 and 2020, natural disasters displaced as many as 300 million people, according to the Internal Displacement Monitoring Centre.[44] The World Bank projects that by 2050, climate change may push over 140 million people in sub-Saharan Africa, South Asia and Latin America to migrate within their countries, away from areas with lower water availability and crop productivity or rising sea level and storm surges.[45]

Looking forward, with more than 10% of the global population living in low elevation coastal zones, "climigration" is likely to increase dramatically as sea level rise threatens the displacement of up to 1.4 billion people.[46] There are already ongoing discussions in Europe about how to accommodate climate refugees from Africa and the Middle East, with growing concern about how to manage political and social stress in the countries or regions that receive the immigrant populations. Two oft-cited scenarios are millions of Bangladeshis moving into India and northern and sub-Saharan African populations into Europe.

Civil unrest and geopolitical conflicts

Climate change-driven scarcity of natural resources may lead to civil unrest, violence and conflict. For example, as freshwater becomes scarcer in certain parts of the world and agricultural production shifts, millions of people will face water and food scarcity.[47]

Indeed, there is already evidence that climate change-linked droughts have led to conflict in parts of Africa

and the Middle East.[48] Three examples illustrate the kind of new risks investors will need to consider:

- A recent report commissioned by US intelligence services highlighted Egypt as a country where climate volatility might induce consequential disruption within a decade, given the reliance on wheat as a dietary staple. Fifty percent of Egypt's wheat production depends on water from the Nile, which flows through Sudan and Ethiopia before entering Egypt.[49] These countries have increasing water needs and also rely on the Nile as a key source.[50]
- Protests over power outages have led to increasing civil unrest in Pakistan over the last decade, with reports of escalating violence, rioters burning trains, looting shops, blocking roads and attacking politicians' homes. An already tight water supply is becoming increasingly stressed, with the World Bank describing Pakistan as "one of the most water-stressed countries in the world."[51]
- A frequently cited geopolitical risk from climate change is the possibility of melting Arctic sea ice leading to increased tensions over newly accessible sea routes and natural resources in the Arctic.

Zoonotic diseases

Climate change is altering the transmission patterns and geographic spread of emerging infectious diseases – 60% of which are zoonotic (that is, transmitted from animal-to-human).[52] Climate change increases the risk of pandemics along two channels: unleashing new zoonotic infectious diseases and increasing the range of territories where existing disease vectors (such as mosquitoes and ticks) can thrive.[53]

The changing climate allows existing infectious diseases, once confined to warmer latitudes, to expand their range. Because warmer average temperatures can mean earlier springs, shorter and milder winters, and longer and hotter summers, conditions become more conducive for many vector-borne diseases. For example, it has broadened the regions with optimal conditions for insect-borne pathogens transmitted by mosquitoes, fleas and ticks – such as Lyme and West Nile disease, malaria, Zika and dengue fever. The new wider ranges for some insects amplify the trend already underway towards more zoonotic spillover from human-caused ecological pressures and disruptions.

Make no mistake, climate change is already a major macro factor impacting growth and productivity. It will continue to be an economic force going forward as the world transitions to a new industrial age that more adequately accounts for the climate risks and externalities that were missing from market pricing in the golden age of fossil fuels. Investors will be on the front lines, making capital allocation decisions that will directly influence this economic transition. It is critical for them to assess how markets view these risks and what may trigger a repricing of assets to more fully reflect the myriad impact from climate change. This is the focus of Chapter 3.

CHAPTER 3

HOW ARE MARKETS PRICING IN CLIMATE RISK?

> *Climate risk will increasingly be reflected in market prices, leading to a potentially dramatic repricing of a range of sectors, assets, companies and securities.*

CHAPTER 3

HOW ARE MARKETS PRICING IN CLIMATE RISK?

Until recently, climate risk was a distant externality, largely uncaptured by market mechanisms and only partially reflected in asset prices. However, this is changing. Climate risk will increasingly be reflected in market prices, leading to a potentially dramatic repricing across asset classes, sectors, companies and individual securities.[54] Indeed, it is no longer a matter of *if* this repricing will occur. Rather, the real question is whether the transition will be an orderly one ushered in by government measures and gradual market adjustments, or an abrupt, sharp decline in market sentiment triggered by a series of climate "Minsky moments." Regardless of the trajectory, the implications for investors' portfolios will be very significant.

This chapter answers three questions that get to the heart of how (and how abruptly) assets will be repriced as climate risk alters the behavior of market participants:

- What aspects of climate change are already reflected in market prices? What aspects are not?
- Why have prices in some markets so far not reflected climate risk?
- What catalysts might cause markets to reprice assets, either gradually or abruptly?

1. What aspects of climate change are mostly priced into asset markets?

A range of climate transition risks have already begun to be reflected in market prices for impacted sectors such as energy, utilities and transportation:

Carbon Emissions Trading

European Union (EU) policies designed to quantify the costs of carbon-intensive goods or services have forced markets to account for future transition risks in today's pricing.[55] After the EU introduced the world's first international emissions trading system (ETS) in 2005, markets began to more efficiently price in transition risk. For example, following the start of Phase 2 in January 2008, European utility equities saw a significant repricing, losing substantial market capitalization. This contributed to Europe's two largest utility companies, E.ON SE and RWE Aktiengesellschaft, losing roughly 90% of their value between 2008 and 2016.

Coal

Globally, there has been a similar repricing of coal. In developed markets, coal demand has been declining due in large part to a range of climate-related policies and pricing competition from less carbon-intensive sources such as natural gas and renewables. Even China, which currently accounts for roughly half of the world's coal consumption, aims to have demand peak by 2030, driven by its pledge to be carbon neutral by 2060.[56] As a result, global coal assets are losing value. It should come as no surprise that coal companies trade at the lowest EV/EBITDA and second lowest average trailing P/E of any industry globally (after money center banks).[57]

Certainly government policy has played a key role in facilitating climate-related repricing. However, in some cases asset markets fail to effectively price in easily observable physical climate risk.

Coastal residential mortgages and municipal debt are examples of assets exposed to obvious climate-driven physical risks. Yet these risks do not appear to be fully recognized by markets. Often structural features of these markets impede market pricing of these risks.

US Municipal Debt

The city of Miami faces significant risk of flooding from sea level rise: according to one estimate, roughly $8.7 billion in residential property alone is at risk of being permanently inundated in Miami-Dade County by 2050.[58] This presents serious problems for the local government, as it generates 35% of its annual operating budget from property taxes.[59] Yet, even with this evident risk, investors continue to buy local municipal debt with seemingly no climate discount. Of course, US municipal debt pricing is far more complex than simply looking at climate risk, but it stands to reason the pricing of Miami's long-term debt should reflect at least some of the tangible climate risk.

There are several reasons why US municipal bond markets do not reflect climate risk. First, well over half of US municipal bonds are held by local retail investors for whom the tax advantages outweigh any long-term climate risk.[60] Second, there is an implicit safety net since the federal government has routinely extended financial assistance to states and municipalities that suffer natural disasters through Federal Emergency Management Agency (FEMA) aid, helping to close the resulting budget shortfalls. Third, while municipal bond disclosures are only now beginning to include climate change risks, many are still backward looking. This means local governments are only required to disclose material risks from events that have already occurred; future climate risk may not fall into this category.

Residential Mortgages

Real estate prices along coasts appear to be reflecting climate risk.[61] However, the market for US residential mortgages often fails to incorporate well-understood climate risks. Mortgage rates do not differ much across states, and where they do, they do not track climate risk. Coastal states such as Florida, Virginia and Maryland – with some of the highest climate risk – also have among the lowest average mortgage rates.[62] While some of the additional risk is accounted for in mandatory flood insurance, many US flood maps are outdated and do not reflect current climate and flood realities. For example, new research by First Street Foundation suggests 14.6 million homes in the US are now at risk from a 100-year flood, almost double what current US federal government maps show.[63]

Furthermore, structural factors in the US residential mortgage market distort pricing of climate risk. Most important among them is that banks can offload their conforming mortgage risk to government-sponsored enterprises (GSEs) such as Fannie Mae and Freddie Mac. Since they typically do not retain the 30-year loans they underwrite, banks originating mortgages have little incentive to account for flood risk in mortgage pricing. For their part, the GSEs depend on outdated flood maps and end up bearing much physical climate risk embedded in the collateral by guaranteeing the mortgages in their securitizations.[64] Investors are largely indifferent to the climate risk embedded in mortgage-backed securities, given the implicit guarantee by the GSEs.

14.6 million homes in the US are at risk from a 100-year flood, almost double what outdated US federal government maps show.

2. Why have other markets not internalized climate risk in asset pricing?

While the previous examples highlight how unique market dynamics discourage markets from pricing in climate change, there are several other factors that apply broadly across markets. In general, these are driven by the unique characteristics of climate change, which are challenging to quantify and predict.

First, investors face the "tragedy of the horizon."[65] The most catastrophic impact of climate change will be felt beyond the typical horizon of most market participants – imposing a cost on future generations that current actors are not particularly keen to internalize now.

Second, a lack of clarity around the timing and location of extreme climate events has created a lack of urgency. For example, there is compelling evidence major hurricanes in the Gulf of Mexico will be more frequent, but there is no way of knowing where they may meet land, or when. This lack of specificity has

led many investors to ignore climate risks altogether or treat them as extreme tail events.

Third, predicting tipping points is notoriously difficult. Climate change is a slow-burning issue with nearly indiscernible impacts on a year-to-year basis but potential for exponential growth once tipping points are reached. Decades of research in cognitive psychology show that humans have difficulty responding to nonlinear relationships.[66] Before a tipping point is realized, most markets simply ignore the mounting risk. These types of risks are especially vexing for markets to price and they typically require a tipping point event that leads to an abrupt repricing all at once. Before a tipping point is realized, most markets simply ignore the mounting risk. For climate change, such an event might be a series of devastating weather events or a truly global agreement on carbon pricing.

> *Climate change is a slow-burning issue with indiscernible impacts on a year-to-year basis but potential for exponential growth once tipping points are reached.*

Fourth, investors are accustomed to the idea of "mean reversion." However, climate change will be different. There will be no reverting back to "normal." As a result, investors rarely consider systemic impacts that do not stabilize over time and have a hard time capturing the full impact of climate change.

Fifth, a lack of universality and consistency in carbon pricing policies has led to "carbon leakage." That is, carbon emissions are simply outsourced from a jurisdiction with high carbon prices to one with low or no prices. According to a recent study, this kind of regulatory arbitrage accounts for roughly 25% of global emissions, as many countries simply import embedded carbon rather than produce it themselves.[67] This kind of regulatory arbitrage enables firms and markets to bypass regulations intended to price carbon more efficiently.

3. What are some potential catalysts for markets to more fully price in climate risk?

Of course, markets that fail to price in an obvious risk can remain "overvalued" for years. Investors too far in front of discounting climate change might find they miss out on years of strong returns before any repricing occurs. As John Maynard Keynes famously remarked, "Markets can stay irrational longer than you can stay solvent."

However, there are several compelling reasons why future markets will not continue to undershoot the price of climate risk. A range of factors will push markets to recognize and acknowledge climate risks and the externalities of carbon emissions. They can provide signals to investors around how and why markets might begin more effectively accounting for climate risk.

When climate change is perceived to have reached a tipping point

There have been enough obvious climate change-driven anomalies and disasters that market participants can no longer ignore them. The 2020 Atlantic hurricane season, for example, has produced more named storms than any prior season.[68] The 2018 California wildfires led to the financial downfall of that state's largest utility company, while the historic 2020 wildfires scorched more than 4 million acres, doubling the previous record.[69] Meanwhile, in Australia, the brushfires that ravaged that country over the past year consumed more than 83 million acres.[70] It's all further evidence that climate change can't be ignored – because it's already here.

Better disclosure and analytics drive a data revolution

According to a PGIM survey of global CIOs, more than 40% do *not* currently incorporate climate change into their investment process. Availability of reliable modeling around the market impact of climate was the most cited hurdle. Fortunately, climate analytics and modelling are finally emerging from academic articles and becoming more accessible for investors. Indeed, the last few years have seen the beginning of what could be called a "data revolution" around

climate risk. Currently, climate data is challenged by a lack of consistency, quality and granularity. While still in its early stages, this trend allows investors to better quantify climate risk and differentiate between firms within an industry. This kind of relative valuation tends to lead to a gradual repricing of assets.

Financial data vendors are beginning to build more climate data into their offerings as well. Bloomberg, for example, now has a wide range of climate-related metrics and analysis accessible to investors on its terminal.[71] The major credit rating agencies have acquired or partnered with climate data specialist firms and are increasingly incorporating climate analytics into their methodologies as well. More sophisticated analysis coming from specialized firms that marry scientific expertise with investment know-how is becoming available to investors as well.

There is another important aspect to the data revolution – investors are clamoring for more uniform and regular data disclosure from their portfolio companies. The process is clearly underway, and investor initiatives that push for standardized climate-related disclosures such as the Task Force on Climate-Related Financial Disclosures are accelerating it. With mounting regulatory and public pressure on firms to track and disclose basic carbon emission metrics and footprints, the amount of usable data for analysis is growing rapidly. As quality climate metrics and data become more available, specialized firms and data platforms will allow investors to more easily integrate climate risk into their investment process. As a result, climate risk will begin to feed into capital allocation decisions and will be increasingly reflected in market pricing.

Policy and regulatory initiatives drive market-pricing of carbon

As discussed, Europe's ETS led to a significant repricing of European utilities. Clearly, this type of government action can play a key role in altering the economics of carbon-intensive assets. Such changes in policy and regulatory regimes can be catalysts for a broader market repricing. As more jurisdictions adopt comparable policy initiatives, a more complete repricing of transition risk is likely to occur globally.

> *Climate risk is feeding into capital allocation decisions and will be increasingly reflected in market pricing.*

Momentum is building, with nearly a quarter of all greenhouse gas (GHG) emissions already covered under a carbon pricing initiative. Of all the schemes, China's ETS is likely to have the largest impact. China leveraged its experience with regional carbon markets and implemented the world's largest national program last year. China's new ETS is expected to cover roughly 1,700 companies from the power sector, accounting for about 30% of national emissions, and will likely lead to some degree of carbon repricing on a global scale.[72]

Central banks and financial regulators may also alter the cost of credit to at-risk industries. The Bank of England, for example, has already announced that it would be setting up climate stress tests for UK lenders and insurers. The idea would be to test how these

companies would fare with more frequent extreme weather events such as severe storms and floods, as well as the implications of suddenly stranded carbon-intensive assets.[73] Even before the tests have been run, this has prompted calls for similar stress tests for other European banks and insurers.[74]

These types of stress tests are just the beginning. From the US Federal Reserve to the Bank of England, to the Reserve Bank of Australia and the Bank of Japan, major central banks are embracing the idea that climate change is a material and systemic risk to the financial system.

> *Shifting preferences of investors and consumers can be a catalyst for the repricing of climate risk.*

Shifting sentiment of investors and consumers

Changes in the preferences of investors and consumers can also catalyze repricing of climate risk. In the case of investors, more than $40 trillion is currently invested in ESG strategies globally.[75] While not all of that is geared towards the "E" component, it is nevertheless telling that some investors already consider climate-related risks and carbon emissions to be material and relevant for them. Even central banks who are becoming a larger part of global bond markets are getting involved. Expectations are growing for the ECB to slash its bond purchases of fossil fuel companies and other heavy carbon emitters.[76] In order to compete for capital, firms must respond to changing investors' preferences or risk relying on a shrinking pool of potential investors and facing a higher cost of capital.

Sharp changes in customer preferences can also drive a repricing of firms or industries that contribute to climate risk. For example, when Europeans altered their travel patterns in 2019 due to greater awareness of global carbon emissions, it led to episodes of "flight-shaming" which caused a highly unusual 9% decline in demand for domestic flights from the prior year in Sweden.[77] As climate change becomes more tangible, there are likely to be more such episodes of collective consumer action.

At a minimum, they represent reputational risk to firms not responsive to the shifting preferences of their customers.

Corporate climate liability

Another potential avenue for the repricing of carbon-based assets is through the courts. To date, no legal challenges against carbon-emitting companies have succeeded in their attempts to seek damages for harm done to the climate – but this is a relatively new field. Of the roughly 1,500 climate cases filed, the vast majority were in the last decade.[78] And with new lines of attack constantly being explored, it's plausible that at some point one of them will succeed. Oil and gas companies are at particular risk from these challenges, which have been brought forward in the US by cities, states and even concerned children.[79]

As was the case with the tobacco industry, all it would take is one successful court challenge for a legal precedent to be set outlining liability for fossil fuel extractors and carbon emitters. This would force investors to reconsider valuations of companies that own or use carbon-intensive assets.

Another avenue by which climate-driven repricing might occur is through the legal interpretation of materiality. This recently was center stage in Australia, where a group of government bond investors sued the Australian government for failing to disclose material investment risks from climate change.[80] Likewise, in the US, there has been growing demand from investors for more expansive climate-related corporate disclosures. This could have a significant impact on how courts view materiality.

The potential for a "climate Minsky moment"

The factors mentioned above are likely to spur gradual or partial repricing of climate-related risks. Policies take years to materialize, legal cases are drawn out and typically build off one another, and new data gets introduced bit by bit. In the absence of these gentle nudges that unfold over time, markets may see abrupt, and disorderly price changes. Former Bank of England Governor Mark Carney referred to a domino-like scenario of markets repricing all at once in short order as a "climate Minsky moment." In such a scenario, all markets price in climate-related events regardless of how far out in the future the risk may be.

This could come in the form of one massive transformative event. According to one estimate, a climate-inspired Minsky moment could lead to global financial losses of up to $20 trillion.[81] However, there need not be a universal abrupt repricing for global markets. There could also be a series of localized ones that impact different realms at different times. It seems more likely different regions and sectors of the market will face localized episodes of sharp repricing, brought on by the sudden realization and internalization of a specific aspect of climate risk. This has arguably already begun.

Markets will play an important role in the economic transition brought about by climate change. This will require wholesale repricing of carbon-intensive assets as well as those that are vulnerable to physical risks. Whether through gradual repricing or abrupt Minsky moments, markets will eventually be forced to more fully price in risks. This has significant implications for investors, regardless of their personal views on climate change. If most market participants believe climate risk is increasing, market pricing will adjust, impacting the holdings of climate activists and skeptics alike. This process is already underway.

As investors monitor markets for these price changes, they will need to begin positioning their portfolios to avoid any pitfalls while also taking advantage of the resulting opportunities. We lay out the most critical and contrarian asset classes and portfolio-wide implications in Chapters 4 and 5, respectively.

CHAPTER 4

INVESTMENT IMPLICATIONS BY ASSET CLASS

> *Markets are inconsistent in accounting for many climate risks, and this mispricing creates opportunities for active investors.*

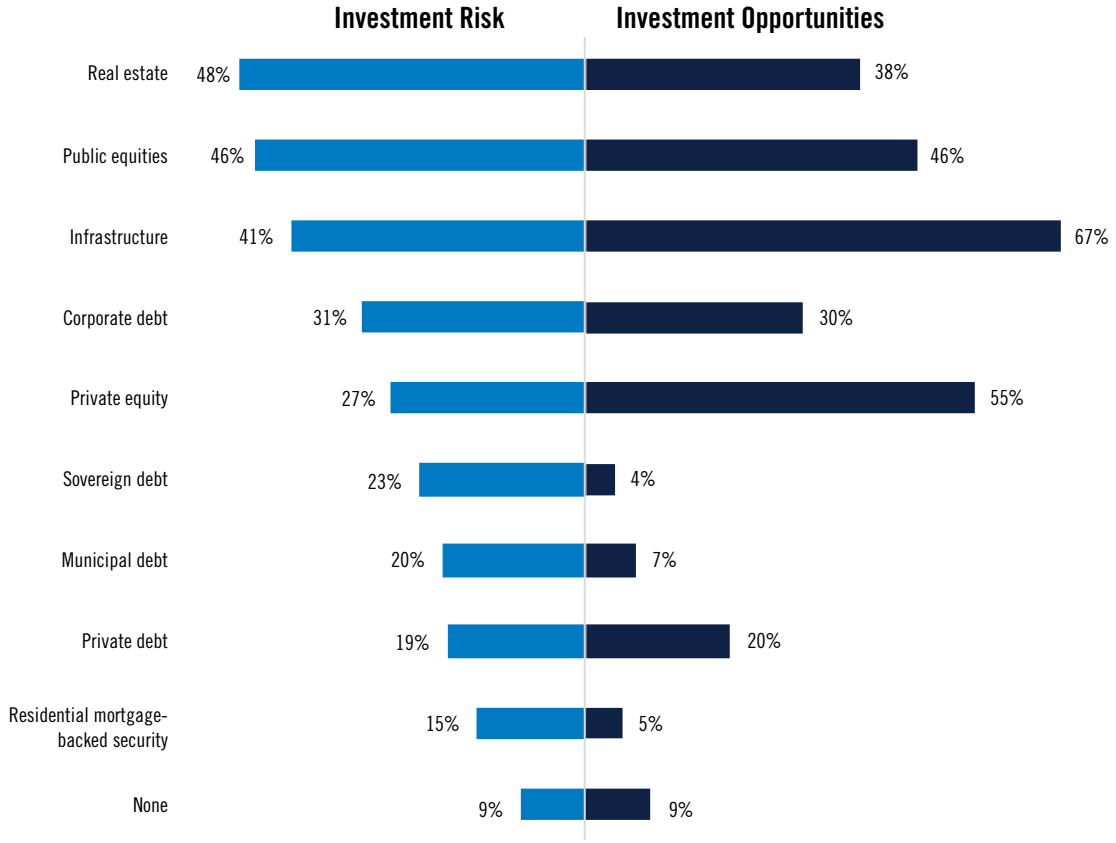
CHAPTER 4

INVESTMENT IMPLICATIONS BY ASSET CLASS

Climate change is no longer a hypothetical risk and is impacting economies and markets today. As such, it is a major material consideration for all investors – regardless of whether or not they tilt towards sustainability objectives. The time has come for long-term investors to view climate change not just as a risk factor in their investment framework but as an opportunity for active alpha[iv] generation along the path to a greener economy.

According to PGIM's proprietary survey on climate change, many investors are not yet at this stage (Exhibit 14). Many opportunities lie in facilitating the transition to a lower-carbon world through innovative and transformative technology. These range from identifying technology-forward companies adept at transitioning to the new "low-carbon economy," to incorporating physical and transition climate risk in analyzing real assets, all the way to providing seed capital to start-ups pioneering technologies

Exhibit 14: **Which of the following asset classes will have substantial investment risks and investment opportunities associated with climate change in the long term?**



Source: PGIM 2020 Climate Change Investor Survey
Note: This survey was conducted along with Greenwich Associates and included 101 participants from across North America, EMEA and APAC. Participants were chief investment officers or senior decision makers at institutional investor organizations including pension plans, insurance companies, endowments, foundations, sovereign wealth funds and central banks.

[iv] Alpha indicates the performance, positive or negative, of an investment when compared against an appropriate standard, typically a group of investments known as a market index.

to reduce carbon emissions. Another aspect of potential opportunity for investors is around markets inconsistently accounting for many climate risks. The resulting mispricing can create opportunities for active investors in public and private markets. Here we lay out the key implications by asset class: public and private fixed income, public and private equity, venture capital and real assets – including real estate, infrastructure and agriculture.

Public and Private Debt

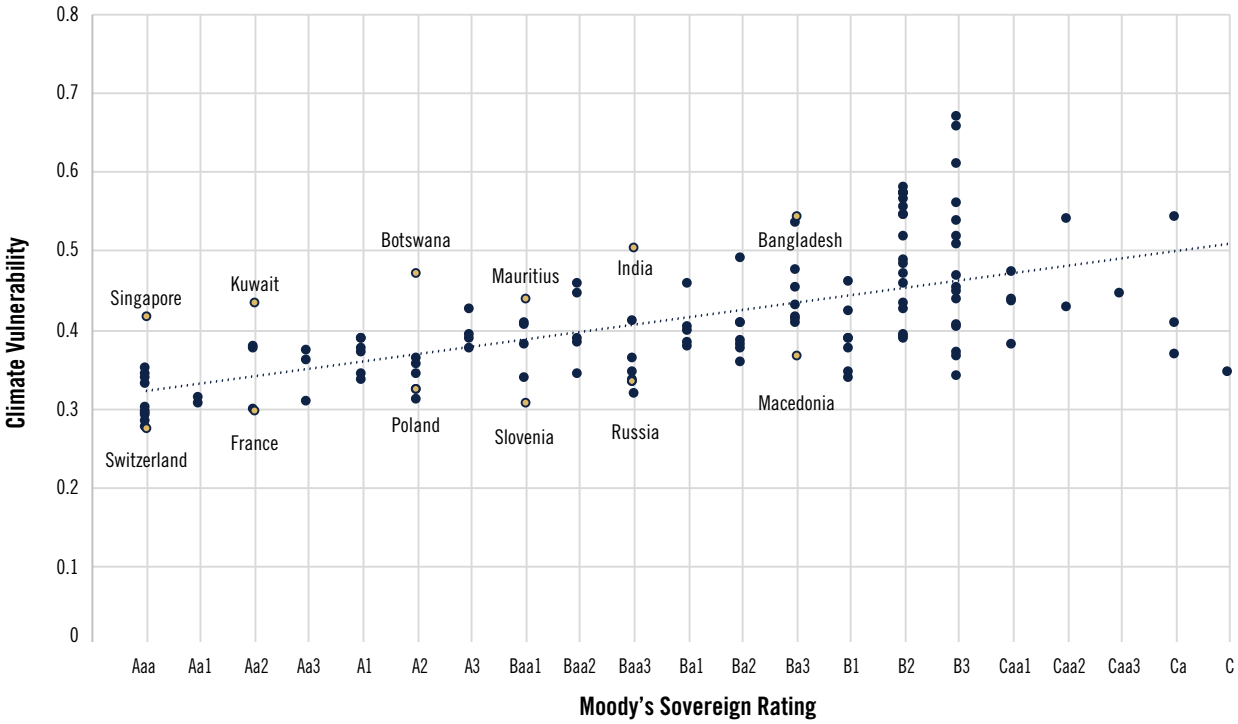
Sovereign Debt: Actively discern between winners and losers where markets do not

PGIM's proprietary survey on climate change indicates that nearly 25% of investors view climate as a risk for sovereign debt, while only 4% view it as an opportunity. This downplays the opportunities arising from the mispricing of climate risk in sovereign debt. That is, countries with similar credit ratings exhibit wide variations in both climate change vulnerability and resilience, allowing investors to take advantage of the eventual repricing of sovereign debt around climate risk (Exhibit 15).

Take Russia and India, for example. As of November 2020, both were rated Baa3 by Moody's – one notch above junk status – with similar default spreads. Of course, climate change is not the sole factor in assessing sovereign credit worthiness, but with regard to physical risk Russia's economy is less vulnerable to climate change.

Understanding the impact of climate change for a country or region comes down to assessing two dimensions: vulnerability and readiness. Vulnerability measures a country's exposure, sensitivity, and capacity to absorb the negative effects of climate change, while readiness measures a country's ability to leverage investment and technology and convert them to adaptation or resilience actions.[82] Investors need to adopt a framework that accounts for both climate vulnerability and readiness – and by analyzing countries using this framework, some meaningful differences emerge.

Exhibit 15: **Sovereign Credit Ratings Don't Capture Climate Vulnerability**



Source: Aswath Damadoran, "Country Default Spreads and Risk Premiums," updated July 1, 2020, accessed July 29, 2020 and Notre Dame Global Adaptation Initiative Country Index, data released July 2020
Note: Climate vulnerability rating is for 2017, Moody's sovereign ratings as of December 2020.

As a stark example, take Bangladesh and the Netherlands. Both face similar risks from rising sea levels – yet the Netherlands has the financial resources and political will to deploy sophisticated technology and urban planning techniques to preserve its territorial integrity even in a scenario with up to a five-meter rise in sea level.[83] By comparison, Bangladesh is projected to lose approximately 11% of its land with a 50-centimeter (or roughly 20 inches) rise in sea level.[84]

For long-term, active investors, the implication is clear: until debt markets begin to fully and efficiently price climate risk, there may be opportunities in the sovereign debt of climate-vulnerable countries that are better prepared – like Singapore and Thailand, whose economies are likely to be less adversely impacted than some of their neighbors. Since spreads don't fully reflect these differences in climate change readiness, active investors should be able to find attractively priced debt opportunities.

The logic of analyzing readiness in tandem with vulnerabilities extends to transition risks as well. Some fossil fuel-exporting countries have more diversified economies and are less dependent on extraction and drilling. When considering transition risk in sovereign debt, investors may want to focus on countries like Mexico and Brazil with economies that are broadly diverse and likely to withstand the decline of fossil fuels better than, say, Angola, Venezuela or Nigeria.

Municipal Bonds: Investors can get climate resilience without foregoing returns

US municipal bonds are an example of a market where climate risks are overlooked. As noted in Chapter 3, one reason for this is climate risk is not a primary consideration for US retail investors – who make up well over half of the market.[85] They are attracted to municipal bonds primarily because of their tax-advantaged status.

For institutional investors with active strategies, this indifference creates opportunities. With little differentiation in pricing, more resilient credits can be available without sacrificing yield. Investors employing a framework that incorporates both risk and readiness can take advantage of this. For example, California faces numerous perils from climate change – from water scarcity to wildfires to agricultural damage. Recent wildfires have crystalized these risks for investors. However, the state government has recently adopted several policies specifically aimed at mitigating fire risk in the future and courts have upheld holding utilities legally liable for wildfires sparked by their power lines.[86] With muni bond markets seemingly more focused on the ongoing fires, long-term investors may benefit from California's ongoing mitigation and resilience efforts without foregoing return.

> *When considering transition risk in sovereign debt, investors may want to focus on countries with economies that are broadly diverse and likely to withstand the decline of fossil fuels.*

Energy Infrastructure: Attractive debt opportunities over the prolonged sunset

For all the attention given to renewable energy (Chapter 2), fossil fuels will continue to play a prominent role in the global energy landscape for decades. Midstream energy infrastructure provides a good example. Not only will it continue to be essential for decades, it will be extremely difficult to replace. In fact, the growing opposition to new pipelines in the US may create a significant barrier to entry, making select pipeline infrastructure more critical and enhancing incumbent pricing power going forward. For debt investors, pipelines offer a stable source of cash flows. Additionally, pipeline companies are relatively insensitive to the price of fossil fuels. Refineries are another example of midstream energy infrastructure that is often overlooked and can provide compelling debt opportunities. Savvy, active debt investors should seek out refineries that are at scale, have the ability to process a range of sweet and sour crude oil and have easy access to natural gas, pipelines and ports.

Property and Casualty Insurance: Innovations in risk-sharing offset higher risks from climate change

Conventional wisdom suggests that as extreme climate events increase in intensity and frequency, property and casualty (P&C) insurers will be left holding the bag for surging insured losses.

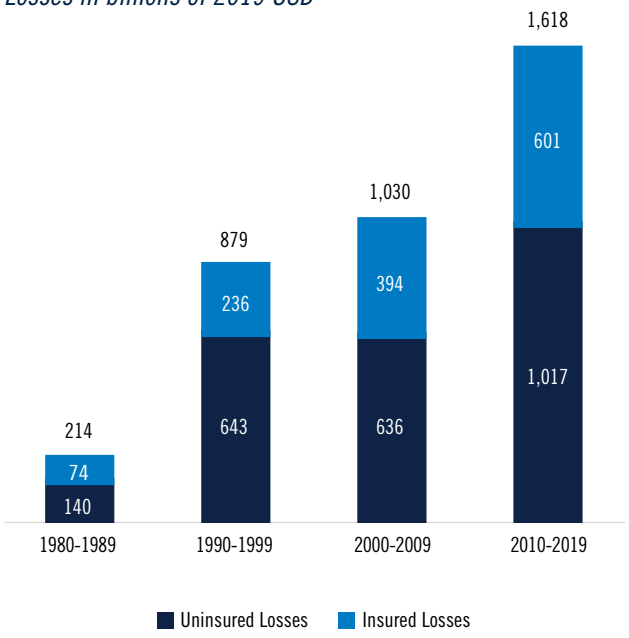
In reality, climate change has made it easier to discern winners and losers within the industry. Several innovations have bolstered the position of the strongest P&C players. First, new capital sources have expanded the loss-absorbing capacity of the industry. For example, innovative risk-sharing structures known as "sidecars" have enabled US insurers to disperse risk by syndicating it to institutional investors globally.[87] Second, top-tier P&C insurers have benefited greatly from advances in climate forecasting and analytics. The combination of enhanced modeling and computing power with granular data has led to a more nuanced understanding of some potential climate change tail risks.

Since many of the weaker players had already exited the market over the past decade, the remaining P&C players are well capitalized and have robust loss absorbing capacity. This was demonstrated in the epic 2017 US hurricane season. Three large hurricanes ravaged major metropolitan areas and unleashed nearly $280 billion in estimated damages.[88] Yet, P&C insurers' diversified earnings largely absorbed the record losses, and the US industry avoided the need to raise meaningful amounts of new capital.[89]

What is often overlooked is that climate change may also create an opportunity for P&C insurers. The portion of the market that is uninsured is several times larger than the insured segment. As changes in the climate become more apparent, it only follows there will be greater US demand for P&C insurance (Exhibit 16). The strongest P&C players like Chubb and Liberty Mutual will leverage the innovations in risk-sharing and capture more of these new opportunities as an increasing number of businesses seek protection from rising climate volatility.

Exhibit 16: **A Widening Protection Gap From Rising Uninsured Losses Creates Opportunity for P&C Insurers**

Losses in billions of 2019 USD



Source: Pinto Suri, "On the Front Lines of Climate Change: The Opportunity in P&C Insurers," PGIM Fixed Income, 2020

Structured Finance: Multiple mechanisms to insulate investors from climate

The risk to physical assets like homes, autos and boats from climate change is evident. However, senior tranches of securitized products backed by these physical assets face low levels of risk as investors are insulated in several ways. First, extreme weather events like hurricanes in the US can create "payment holidays" for mortgages and auto loans and these forbearance measures can disrupt cash flows. However, the cash flow structure of securitizations has specific mechanisms designed to be resilient and insulate senior tranche investors from temporary disruptions.

Second, with physical risk to the underlying assets, location matters. Automobiles in California are more prone to fire and flood risk than those in Montana, for example. The pool of collateral that supports asset-backed securities (ABS) are deliberately designed to diversify such regionally concentrated risks.

Finally, aside from the resilient cash flow structure and the geographic distribution of collateral pools, investors in agency mortgage-backed securities (MBS) have additional protection from climate risk. All the mortgages within an agency MBS are guaranteed by government-sponsored entities like Fannie Mae and Freddie Mac – whose policies prevent them from considering regional factors such as climate change. The net effect is, mortgage investors are insured against climate risk by the federal government.

Public and Private Equity

Disaggregating common categories can sharpen insight into climate risk – and opportunity

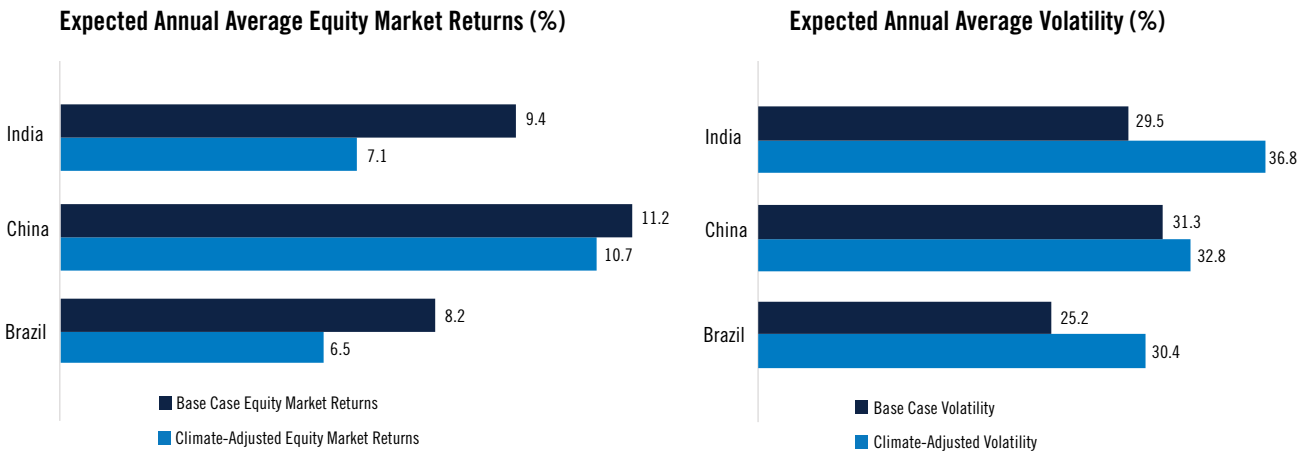
One consequence of the widely uneven impact of climate across regions and sectors is that aggregated views can really distort perceptions of climate risk. Disaggregating commonly used equity categories can help identify winners and losers. For example, large emerging markets such as China, Brazil and India share long-term growth potential. Yet, even within this grouping of countries, climate change will have drastically different impacts. While the aggregated impact across these large emerging markets is projected by many to be modest, recent research by QMA suggests that climate change will impact the economic growth of these countries and their equity returns in strikingly divergent ways. Climate, for instance, is expected to curtail annual economic growth by almost 3% in India and long-term equity market returns by more than 2% annually. By contrast, the hit to growth and equity returns in China from climate change is much more muted (Exhibit 17).

Evaluate the optimal approach to advance ESG objectives

Excluding "dirty" industries, like fossil fuel extraction, from portfolios has been a tenet of ESG investing for many institutional investors. For early ESG adopters, this method made sense – especially given the scarcity of data at the individual company level, the ease of implementation across their portfolio and the clarity of the approach in communications with stakeholders.

While pure exclusion may certainly be the appropriate way to meet portfolio and beneficiary objectives for many investors even today, some ESG-focused investors may also want to evaluate alternative approaches to achieve climate-related goals and fiduciary objectives. Put simply, fossil fuels, as Chapter 2 explained, will remain a major source of global energy supply for decades – despite the ongoing and necessary transition to a low-carbon economy.[90] The reality of this protracted sunset might prompt some investors to reconsider banishing fossil fuels altogether from their portfolios for three reasons.

Exhibit 17: **Climate Change Impact on Select EM Equity Returns and Volatility**



Source: QMA analysis
Note: Negative GDP growth impact from climate change also increases expected volatility in equity markets.

First, it is now easier to identify the greenest firms within an industry. Greater availability of climate analytics – based on an expanding array of firm-level carbon emission and other metrics – make it possible to differentiate and go beyond a "one size fits all" characterization of all firms within an excluded sector. One benefit of better corporate climate disclosures (however imperfect they may be) is they enable investors to have a more nuanced, data-driven view of the good and bad players within an industry.

Second, given how much of the fossil fuel sector is priced for imminent obsolescence, there are compelling reasons to expect the greenest firms to outperform. Leaning into greener technologies and fuel sources will enable forward-looking fossil fuel companies to navigate the long, slow transition to a low-carbon world. It may even be an enduring source of competitive advantage for these firms – many of which have the scale to fund, develop and deploy innovative new green technologies and processes. For example, oil majors like Total and Shell that are more willing to embrace the transition to a low-carbon world will face a materially lower risk of obsolescence than their peers. As oil producers unable to adjust begin to shutter, the "last firms standing" will be able to capture a larger portion of the remaining market.

Investors will need to recognize no single approach is suitable for all oil majors here. They will want to focus on firms that leverage their existing strengths while shifting to green activities. For instance, oil majors with expertise in offshore oil and gas exploration are better placed to transition to offshore wind power. And oil companies with strength in deep mining or fracking may be better suited to explore carbon storage techniques – essentially the reverse process of drilling.

Last, even for ESG-focused investors, differentiating between good and bad players in the industry can have a significant constructive impact during this lengthy sunset. Public and private equity owners can actively influence fossil fuel users and extractors to employ more sustainable practices. Since fossil fuels will be essential for decades under almost all energy use scenarios, a pragmatic approach for some ESG investors may be to encourage use of the cleanest fossil fuels (e.g., LNG and natural gas) and eschew dirtier options like coal. By actively engaging with these companies – rather than excluding them – a group of like-minded shareholders can positively impact carbon emission outcomes over the decadeslong wind-down period for fossil fuels. Indeed, groups of investors are already influencing major oil players.[91]

> *Investors can influence fossil fuel users and extractors to fund, develop and deploy greener technology and practices.*

Greener power generation

Public and private equity investors may also find attractive opportunities in energy-efficient utilities. High-carbon assets like coal-powered generators will continue to be displaced by cleaner alternatives like natural gas and eventually renewable power sources. Electricity-generating firms that lean on cleaner energy sources today are attractive investments even at current valuations.

In Europe, for example, carbon trading has accelerated this transition and made utilities more mindful of their carbon emissions, pushing them to move away from the dirtiest fossil fuels towards cleaner ones. EU officials have proposed a European Green Deal to make the union climate neutral by 2050.[92] A major component of this is transforming the power industry, which emits 75% of the EU's greenhouse gas emissions.[93]

While the capacity of renewables is growing along with demand for green energy, the need for smart transmissions networks that integrate renewable and fossil fuel sources is immense. Wind and solar projects often generate power in remote areas. Transmitting this power to urban population centers and integrating fossil fuel sources as well is a vital part of the energy landscape.

On the demand side, companies that boost efficient consumption by households and businesses can provide good opportunities for public and private equity investors such as smart meters that allow industrial and individual consumers to better understand and manage their electricity consumption.

Venture Capital

The transition to a low-carbon world can be accelerated with innovative technologies, many of which are materializing in venture capital markets:

New analytics and alternative data sources

The climate data revolution plays an important role in resilience and adaptation technologies. This includes advanced agriculture and microclimate analytics to help the food production industry anticipate and respond to weather variability. Additionally, advances in catastrophe risk modeling and digital mapping help manage and reduce risk for reinsurers, financial companies and owners of physical assets and infrastructure.

> *The need for smart transmission networks that integrate renewable and fossil fuel sources is immense.*

Next-generation construction

Innovative materials for construction are another area for resilience investing. For example, novel coatings and additives for paint have been developed that reduce heat absorption for buildings and transportation equipment. This has very practical and immediate uses as these coatings can reduce cooling costs by as much as 20%.[94]

Enabling renewable energy

One of the biggest hurdles for renewable energy is its intermittency. Storing energy in batteries is the most obvious answer and capacity of utility-scale batteries quadrupled between 2014 and 2019.[95] Other means of energy storage for utilities and power-generating plants are key areas for innovation.[96] Pumped storage hydropower – where volumes of water are pumped to various elevations by excess power and then allowed to flow downward to generate power when it is needed – is not new technology, but remains one efficient way to store energy at scale. Additionally, smart grids and more-efficient transmission networks can help to integrate renewable sources more broadly than they are currently. Innovations around superconductive alloys could also help reduce waste in long-distance high-voltage transmission lines, with waste running from 6% of power transmitted in the US to almost 20% in Brazil and India.[97] Looking ahead, so-called "room-temperature superconductors," such as ceramics and metallic alloys, hold the promise of eliminating much of the waste from power transmission today.[98]

Ground transportation

Scaling down the carbon footprint of cars, trucks and buses provides an opportunity for reducing global carbon emissions substantially. Manufacturers of key components for electric vehicles (EV) are a natural area for investors to explore. For example, continued innovations in battery storage, recharging efficiency and cost of production are essential for widespread use of EV in ground transport. Currently, more than three-quarters of charging is conducted at home by US owners and operators of EV.[99] As a result, their use is limited primarily to short trips – like city buses and local deliveries.

Hydrogen

One potentially transformative innovation is hydrogen-powered cells, which can generate immense energy yet recharge within minutes. Their only byproduct is water. This might be useful in sectors that have been resistant to decarbonizing, for example in steel and cement production where they can generate the intensity of heat required for those manufacturing processes. Over time, hydrogen cells could power long-distance trucks, high-speed trains, tanker ships or even airplanes.[100]

One challenge for hydrogen is that the most common way to produce it requires fossil fuels. However, a greener hydrogen-based energy source has been a central component of green fiscal stimulus plans in Europe and Asia.[101] For example, the North Sea is emerging as a hub for production of "green hydrogen" with numerous projects underway using offshore wind power.[102] Furthermore, infrastructure to support storage and distribution as well as a pipeline for tankers will be coming online.[103]

In the US, there are also efforts underway to use excess power from nuclear plants to create green hydrogen. For example, this is currently being explored at the Palo Verde Nuclear Generating Station in Arizona. Nuclear plants not only view this as an environmental

solution, but also an economic way to manage the negative pricing that occurs when other electricity sources such as solar dominate the grid.[104]

Governments are eager to push hydrogen power forward for several reasons: it helps them meet decarbonization commitments, address energy independence vulnerabilities and is an effective response to mounting pressure for climate action. The billions of dollars committed to the space could potentially help accelerate industrialization and scalability of hydrogen fuel cell technology, reduce costs and encourage adoption.

Carbon capture and storage

Carbon capture and storage (CCS) is perhaps the most speculative category, but also holds the most upside for transformative change. The International Energy Agency has called for a 20-fold increase in carbon capture capacity over the next decade in order to meet climate goals. For industries that face difficulties in slashing carbon emissions (like airlines) or that are concerned the carbon offset market may not scale up fast enough for them, carbon capture and storage can be especially attractive.[105] Yet, investment in this space over the last decade is less than 1% of the investment in renewable power.[106]

This is partly because current approaches to CCS are quite limited and not very cost-effective. However, there are several reasons to monitor the space. First, there is real promise in increasing the efficiency of carbon capture; innovative techniques around capture and storage are already emerging in research labs. Second, there has been progress in redeploying the collected carbon for industrial uses like curing concrete, creating industrial lubricants, or even as an input into synthetic jet fuel.[107] Creating some industrial demand for the captured carbon could meaningfully improve the cost efficiency of CCS.

Of course, the holy grail is direct air carbon capture and storage. That is, plucking carbon dioxide directly from the air (powered by renewable energy, of course) and storing it deep underground in a solid state. The technologies to achieve this immense undertaking are nascent and scattered across the startup landscape. One Swiss firm has taken meaningful strides in this area, partnering with similar firms in Iceland and Canada to consolidate complementary technology and offer an integrated solution. However, it comes at the hefty price of $250 per metric ton of carbon – or roughly 10 times the going rate for carbon offsets on the European ETS.[108]

> *Hydrogen powered cells can generate immense energy yet fully recharge within minutes.*

Real Assets

Real Estate: Integrating climate change into the investment process

Incorporating climate change risks and mitigation costs into the heart of the real estate investment process can not only help manage physical risks but can also generate additional investment opportunities.

First, capital investments to bolster climate resilience can be attractive for equity owners. The adage "an ounce of prevention is often worth more than a pound of cure" certainly applies here. Capital projects will detract from cash flows and operating incomes in the near term and may not be sensible for real estate debt providers. But direct real estate equity owners are more likely to see the payback when such projects prevent large losses and preserve cash flows later. Simple renovations like elevating the electricals a foot or two off the ground may make sense for properties in vulnerable areas. In fact, such resilience projects have shown to not only keep the lights on but, more importantly, keep tenants in place during extreme events and maintain steady lease payment cash flows. Additionally, while assets with a strong resilience strategy don't currently see any beneficial pricing in the insurance markets, it's likely this will change in the coming years. This would further decrease operating expenses for asset owners.

Second, by employing cutting-edge data and leveraging their own climate analytics, data-conscious real estate investors can be thoughtful in uncovering situations where the broader market sees limited value. For example, investors can consider high-risk locations by factoring in resilience-boosting capex into their models

for capitalization rates and cash flows (Exhibit 18). By integrating these improvements into their investment process, investors can tap into attractive opportunities where markets may overshoot.

Third, with more high-end office and retail space customers demanding certified "green" properties, the additional cost of energy efficient renovations or construction can be offset by attracting and retaining tenants seeking climate-differentiated properties and willing to pay a premium for it.

Infrastructure: Desalination, renewables and charging stations

Solar and wind projects in Latin America

With many investors eager to support wind and solar projects, the US and Europe are relatively saturated markets. Investors should find higher returns for solar and wind projects in South American countries such as Chile and Uruguay. With an aging network of hydroelectric power suffering from declines in river flow and unable to cope with rising demand for power, South America is full of opportunity for renewable energy generation. Wind and solar projects are in demand there to replace vast hydroelectric networks.

Charging stations

There are opportunities to enhance cash flow of private toll roads and other road-related infrastructure such as the motorway services and plaza businesses by adding electric charging stations. As EV transport becomes more popular for long-haul trips, there will be growing demand for on-route charging. With so few charging stations on most US highways and related infrastructure, this can be an opportunity for road infrastructure owners to generate a new revenue stream and increase their assets' usage.

Water infrastructure

Less predictable rainfall due to weather variability creates opportunities for water desalination plants, water transport and water storage. As water is highly regulated in most jurisdictions, investors should mainly focus on markets with a straightforward regulatory landscape and strong property rights. Australia, which has historically relied on rainfall for much of its clean water, is a favorable market for water desalination given its projected rain shortages and supportive regulatory environment. Other opportunities are arising in water filtration (turning brown water into white water) in the US and Latin America.

Agriculture: Ag tech drives a range of new investment opportunities

Inconsistent and unpredictable temperatures, precipitation and aridity is a serious threat to crop yields. Investors may want to evaluate the significant business opportunities in the next generation of agrarian business models and the associated technologies.

Precision agriculture

Investors in farmland should look to partner with farming operators that leverage precision

Exhibit 18: **Integrating Climate Change Into the Real Estate Investment Process Requires Innovative Data (Illustrative)**

Site	Primary Type	Average Risk	Earthquakes	Floods	Heat Stress	Hurricanes & Typhoons	Sea Level Rise	Water Stress
11 Filmore Street	Office	36	83	52	41	0	0	84
7825 W Ash	Healthcare	25	0	7	45	25	0	46
4th Cell Ave	Retail	62	0	7	39	46	40	58
15 Valley Park	Warehouse/Storage	35	0	5	66	62	0	44
5th & Broadway	Office	21	83	7	37	0	0	61
2400 Park Ave	Office	31	83	75	44	0	0	35
440 Elmo Road	Office	40	85	61	42	0	0	94
St. Allen	Healthcare	25	0	7	45	25	0	46
La Vie on 5th	Residential	46	0	46	60	64	0	44
Park Cir #2	Warehouse/Storage	25	0	8	51	0	0	64

Source: Measurabl and Four Twenty Seven, accessed 2020
Note: Illustrative data, properties do not reflect actual PGIM holdings

agriculture techniques to manage rising weather variability. These technologies now go well beyond drip irrigation systems and subterranean drainage systems.[109] Many employ real-time farm monitoring and advanced weather forecasting, for example, to trigger underground root warmers to spare crops from unexpected frosts and help guard against unseasonal drops in temperature. Sensors, GPS and variable rate technologies can also adjust crop inputs like water, fertilizer and pesticides based on current and expected soil conditions. Similarly, the market for agricultural drones and robotics is growing rapidly. Collectively, it is estimated that the next generation of ag tech could be a $250 billion annual business by 2030.[110]

Smaller and more resilient farms

Smaller scale farms present another investable application of ag tech to help ensure food systems remain resilient to climate change. As weather patterns shift and food production seasons in some areas become shorter, small-scale farmers can leverage new tactics and seize opportunities for production in areas beyond current fertile zones. Protected crop cultivation techniques can shield crops from adverse climate and weather. Greenhouse horticulture, for example, can still thrive in warming regions like the Middle East and Africa, even as crop yields from large-scale farming are adversely impacted by climate change. Vertical farming in warehouses also presents some opportunities for investors, as these small-scale farms located closer to urban markets can be more resilient to weather variability.

Alternative protein

Livestock production accounts for 15% of global greenhouse gases and has led to the potential for significant growth in alternative proteins for consumers conscious about their health or the climate.[111] It may be hard to replace a ribeye steak, but there has been significant success with plant-based burgers, sausages and ground beef – now even sold in Burger King and McDonald's.[112] Similarly, there are opportunities in plant-based dairy options like soy, oat and almond milk, that may offer higher returns than conventional dairy. Although some of these crops are water-intensive.

Solar farm land leasing

Farmland investors may be able to enhance yields by leasing land to solar farm developers. Solar panels are most productive in areas with high sun exposure, light wind, moderate temperatures and low humidity – the same conditions required for growing most agricultural crops.[113] As a result, solar developers have been paying farmland owners favorable lease terms to convert their agricultural land into solar farms. This is most profitable for farmland investors that own plots close to urban centers where electricity demand is highest.

Renewable natural gas rises

Agricultural waste is the largest contributor of methane gas, accounting for about 20% of global emissions.[114] Driven by pressure from consumer preferences for sustainability, more innovative techniques are emerging to make farming greener. For example, agricultural waste is typically stored in vast open lagoons where it emits methane – a GHG 25 times as potent as carbon dioxide – for decades. However, new innovations have emerged that can transform organic waste product into biomethane, or renewable natural gas (RNG).[115] Companies are working with dairy farms to install biodigesters, which use specialized bacteria to convert their organic waste into biogas which can be purified into RNG.

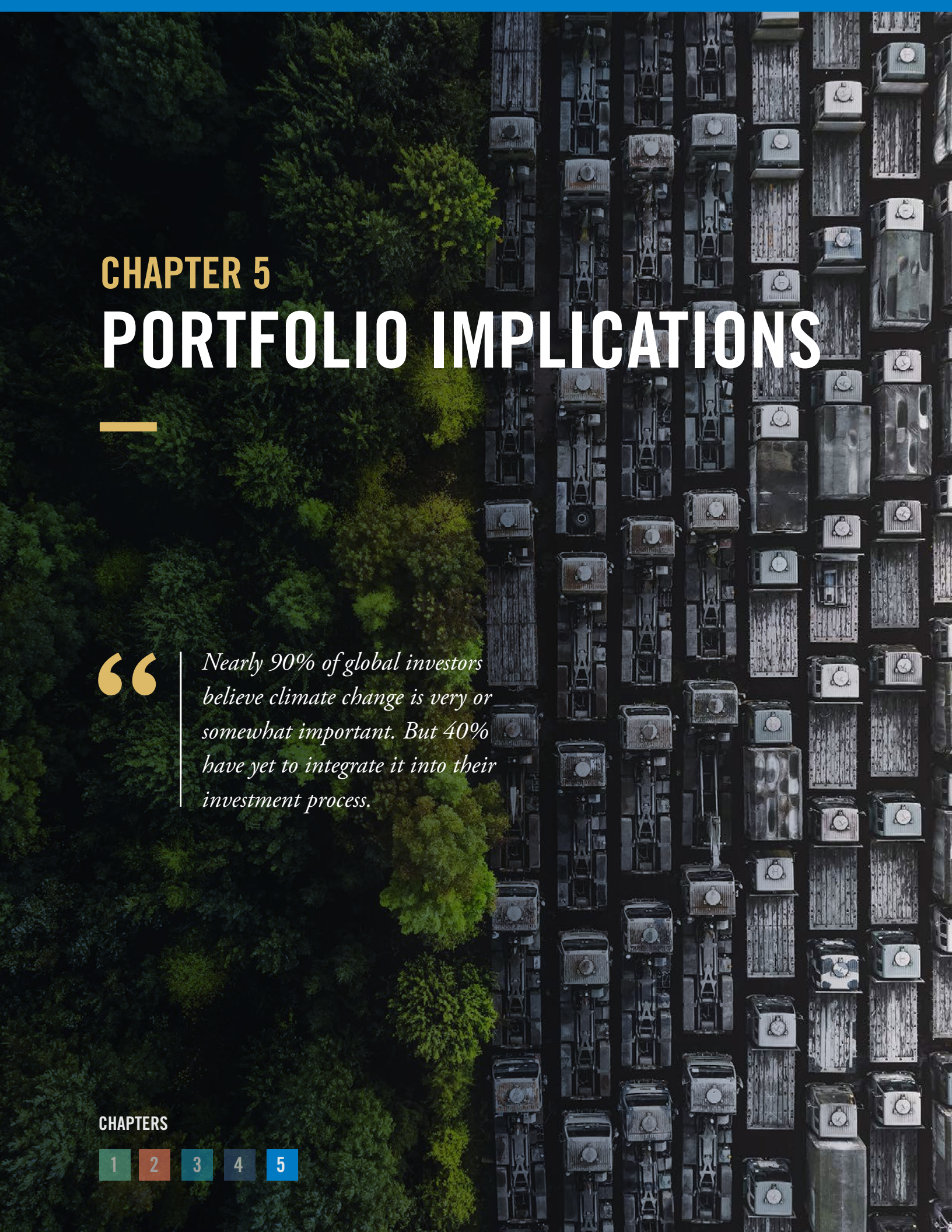
Tapping into a growing market for carbon offsets

Looking ahead, reforestation projects may see new opportunities for growth in corporate carbon offsetting. A growing number of companies have pledged carbon neutral footprints. As more companies take these pledges, many will fall short of carbon neutrality in their internal operations and will seek external carbon offsets. Reforestation projects, or even young timberland, can be a source of verifiable carbon offsetting for corporations.

Chapter 4 examined the significant investment opportunities and risks for individual asset classes (Table 2). However, the sweeping changes resulting from climate change also have profound implications for chief investment officers across the entire portfolio. We turn to these implications in Chapter 5, where we propose a portfolio-wide climate change action plan for institutional investors.

Table 2: **Asset Class Implications Summary**

Fixed Income: Mispricing Creates Long-term Opportunities for Active Investors	
Sovereign Debt	■ Adopt a framework that considers both climate vulnerability and readiness ■ Opportunities for active investors to discern between winners and losers where markets do not
US Municipal Bonds	■ With most muni investors motivated by favorable US tax treatment, climate risk is largely overlooked ■ Long-term active investors can find climate-resilient municipal debt without foregoing yield
Energy Infrastructure	■ The long sunset for fossil fuels creates opportunities in midstream energy infrastructure (e.g., pipelines and refineries)
US Property and Casualty Insurance	■ New sources of capital and advances in underwriting have enabled top P&C insurers to better manage exposures ■ Climate events are likely to drive US demand for P&C coverage and expand the market for the top players
Structured Finance	■ Investors are structurally insulated from physical risks to underlying collateral in ABS ■ In the agency MBS market, government-sponsored entities absorb much of the climate risk around the underlying properties, not investors
Public / Private Equity and Venture Capital: Navigating the Green Transition and Game-changing Technologies	
Public and Private Equity	■ Significant divergence in climate sensitivity across sectors and countries creates opportunities for discerning, active equity investors ■ Capture opportunities for long-term outperformance with the "greenest" firms within brown industries. ■ For ESG-focused investors, evaluate the benefits of pure exclusionary approaches vs. selective engagement with fossil fuel companies given their long sunset and improved data disclosures
Venture Capital	■ Evaluate potentially transformative early-stage technologies: hydrogen power and carbon capture and storage ■ Integration of renewable energy with better power storage, smart grids and superconductive transmission networks ■ Electric vehicles: Seek technological innovations in key components like improved battery storage and recharging efficiency ■ Cutting-edge climate forecasting, analytics and modeling tools to help manage and reduce risk for the financial, agriculture and infrastructure sectors ■ Next-generation construction materials like exterior paint that reduces heat absorption and cooling costs
Real Assets: Deploying Technology to Protect Assets and Uncover Opportunities	
Real Estate	■ Leverage next-generation climate analytics to capture opportunities where the broad market sees mostly risk ■ Consider capital projects to enhance climate resilience of high-risk properties that make lease payments more durable
Infrastructure	■ Aging energy infrastructure creates new opportunities in solar and wind projects in Latin America ■ Less predictable rainfall creates new investment opportunities in water desalination, transport and filtration ■ Enhance cash flows and increase usage of toll roads by installing electric vehicle charging stations and plazas
Agriculture	■ Ag tech innovations: Deploy advanced root sensors, vertical farming, drip irrigation and variable rate technology to adapt to changing weather patterns ■ Generate renewable natural gas from livestock production ■ Shifting consumer preferences for alternative protein creates opportunities ■ Reforestation and timberland: Capture growing corporate demand for verifiable carbon offsets to fulfill climate pledges



CHAPTER 5

PORTFOLIO IMPLICATIONS

> *Nearly 90% of global investors believe climate change is very or somewhat important. But 40% have yet to integrate it into their investment process.*

CHAPTER 5

PORTFOLIO IMPLICATIONS

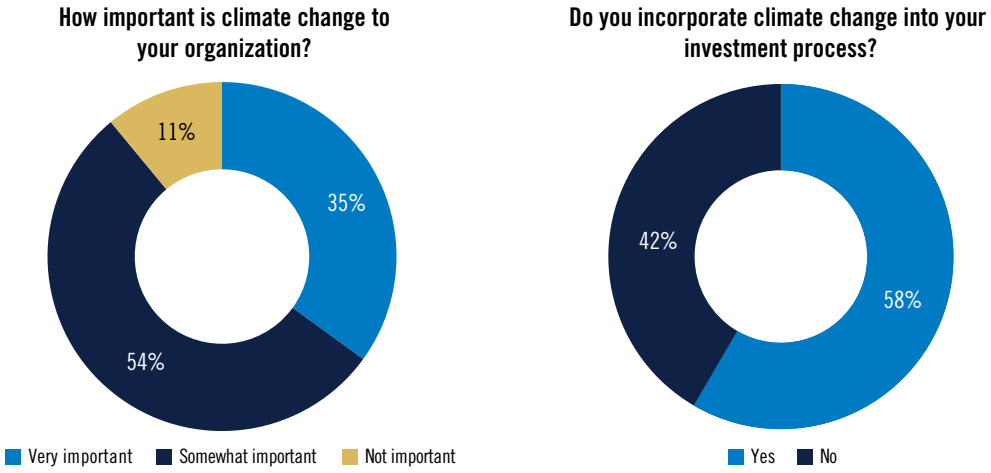
Investors can no longer ignore climate change in their portfolios. Yet, many investors don't have a comprehensive plan for addressing it. According to PGIM's proprietary survey of over 100 institutional investors, nearly 90% of global investors believe climate change is very or somewhat important. However, over 40% have done little to integrate it into their investment process (Exhibit 19).

Overall, climate change presents a set of multi-dimensional risks that are difficult to capture and empirically analyze using historical data and linear models. The potential impact of rising sea levels and flooding on coastal cities like Mumbai and Miami is apparent. What is less evident are the hidden risks embedded in individual companies and portfolios. In fact, these hidden risks are material for a range of industries not commonly thought of as highly exposed to climate risk. Likewise, the best opportunities for investors may not be conveniently branded as "green." In other words, a simplistic strategy that divides the investment world into "brown" villains and "green" heroes is not the most effective approach to achieve environmental or fiduciary objectives. Below we present an action plan for institutional investors considering the holistic impact of climate change across their portfolios.

1. Use alternative data sources and techniques to better understand cross-portfolio climate risk

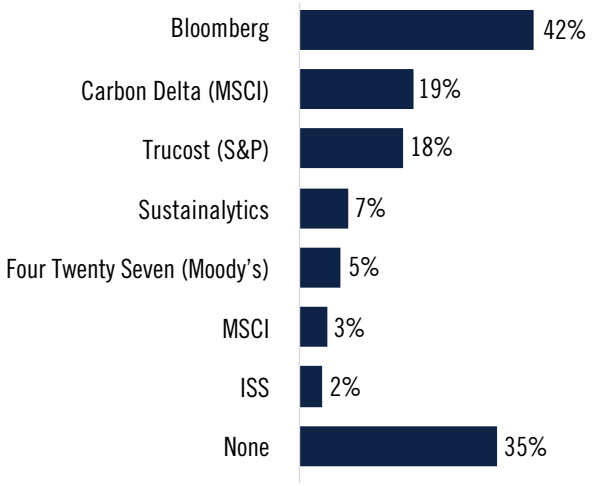
Measuring portfolio-level climate risk can be daunting given the complexity of the risks and the inconsistency in data quality and granularity. Risk managers accustomed to standard, uniform measures of risk they can apply across asset classes are bereft with regard to climate risk. High-quality data and metrics are simply not available across all asset classes.

Exhibit 19: **PGIM Survey of Global CIOs**



Source: PGIM 2020 Climate Change Investor Survey

Exhibit 20: **Investors Use a Range of Vendors for Climate-Related Data and Analytics**



Source: PGIM 2020 Climate Change Investor Survey

To evaluate the full extent of their portfolio's exposure to both transition and physical risk, CIOs will need to go beyond conventional data resources and methodologies and adopt an unorthodox approach. According to PGIM's survey of global CIOs who already incorporate climate change, fewer than one in five utilize alternative data such as satellite imagery, flooding maps, drought data and air quality data.

Transition risk

For publicly listed companies, detailed data availability around transition risks – such as carbon emissions and carbon footprint – has increased significantly in the last few years. Sustained stakeholder pressure has led to many public companies reporting at least basic carbon emission data, albeit inconsistently. In parallel, a wide array of climate data analytics companies has emerged that use data to devise rating systems and metrics for virtually all publicly traded companies (Exhibit 20).

When considering climate risk at the individual security level, it is important for investors to remember that the absolute rating for a firm matters less than its relative rating against its peers. That is, the individual rating for Volkswagen in a particular rating methodology is less important than how it compares to Toyota and Ford. For this reason, investors may be better served to choose a single provider with a consistent methodology who can cover ratings across the widest swath of geographies, sectors and firms rather than selecting the best player in each sector or region.

By aggregating the corporate-level data, climate analytics firms can provide some basic portfolio-level metrics enabling CIOs to get a clear picture of the embedded carbon exposure across their public debt and equity portfolios. This also enables CIOs to get a feel for the embedded transition risk, or which portions of their portfolio are at greatest risk from environmental policy changes such as carbon pricing schemes. Once they have a sense of their carbon exposure, CIOs can consider hedging strategies using environmental commodities like carbon offsets.

> *Climate analytics firms can provide some portfolio-level metrics so CIOs can get a feel for their embedded carbon exposure.*

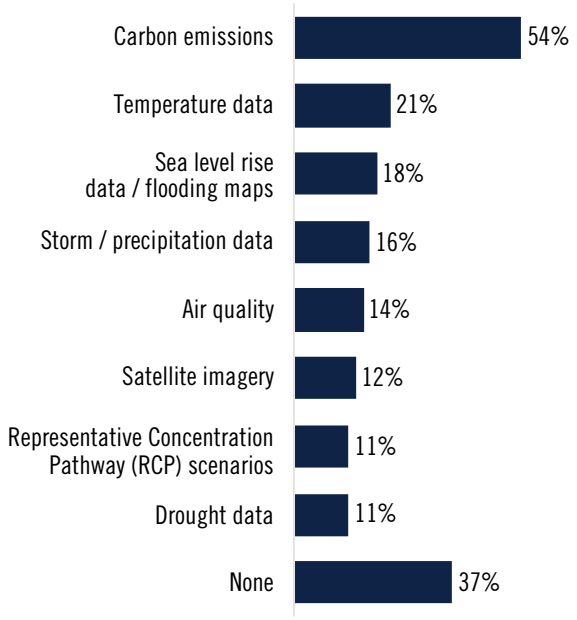
For private markets, visibility into company-level climate risk is limited. Privately held companies face few of the public pressures listed firms face to measure and publish their carbon footprint and other relevant metrics. With little to no data available it is much more challenging to assess transition risk for private equity (PE) investments, for instance, and CIOs will need to invest the time to get comfortable with the methodologies deployed by climate data providers and be aware of the significant data limitations.

Physical risk

When it comes to physical risk, the geolocation of critical real assets can be overlaid with predictive scenarios for drought, extreme heat and flooding. While sophisticated infrastructure and real estate investors have been doing this for some time, new capabilities in geolocation technology and climate analytics enable even equity and debt investors to assess their portfolio's exposure to physical risk (Exhibit 21). The very same geolocation and forecast overlay techniques can be applied to assess physical risk around the critical real assets of companies – including production facilities, data centers, assembly plants, distribution centers and even key suppliers.

Once again, CIOs will need to be thoughtful about the methodologies employed by their analytics

Exhibit 21: **Few Investors Go Beyond Carbon Emissions When Incorporating Alternative Data**



Source: PGIM 2020 Climate Change Investor Survey

providers, seeking providers that deploy transparent, peer-reviewed models rather than proprietary "black-box" models. The field of climate research is evolving rapidly, with new research being published almost daily. CIOs will also want to ensure their analytics providers continuously update their models using new, cutting-edge research. Analytics firms that monitor and incorporate the most current thinking will be able to develop the most useful models for investors.

CIOs and risk managers can't rely on off-the-shelf risk data metrics when assessing the climate risk of a multi-asset portfolio. This demands a more dynamic approach that involves different techniques and metrics for each asset class.

2. Integrate climate change into portfolio risk management analytics

There are three distinct choices that CIOs will want to consider when incorporating climate change into portfolio risk management.

First, the most basic – and perhaps the most useful – climate risk analysis recognizes the next decade of climate change is largely predetermined. This approach does not require complex climate scenario modeling stretching into the distant future. Rather, it simply looks at every holding in the portfolio in terms of its exposure to near-term, fairly predictable climate-driven risks to assess the degree and nature of climate exposure. In the case of real assets, for example, this would require overlaying the location of real estate, infrastructure and agricultural holdings on top of maps that specify areas with elevated risk of flooding, severe storms, water stress and extreme heat. This fundamental geographic analysis can be extended to public equity and debt securities where data on location of key production facilities is available. This analysis should, in particular, highlight assets with lengthy lock-up periods or long maturities.

> *The geolocation of critical real assets can be overlaid with predictive scenarios for drought, extreme heat and flooding.*

In a similar fashion, a heat map can be constructed for debt and equity exposures to sectors with high climate risk – as well as sectors with upside associated with the transition to renewables. The resulting climate risk and opportunity heat map can provide CIOs with a multi-asset view on the portfolio's vulnerability to climate risk as well as exposure to opportunities resulting from a transition to greener energy sources and technologies. From a practical standpoint, the output from a rigorous climate risk analysis can inform decisions on reducing (or increasing) exposures to regions, sectors or companies.

Second, institutional investors may want to conduct targeted climate stress tests. These tests could be at the issuer or asset class level for a specific parameter – like a potential policy response (e.g., higher carbon prices)

or a specific future physical risk (e.g., water stress) in a specified region. By keeping the scope of climate stress tests focused on a specific policy or risk, investors can often generate actionable results that can concretely inform investment decisions. A note of caution here: to the extent this analysis relies on incomplete or unstandardized data, or the requisite data has long lags (like carbon emissions data) the results need to be interpreted with an appropriate margin of error. Nevertheless, as data quality and transparency improve, there is clearly an opportunity for investors to explore targeted climate stress testing. Of the investors who currently do incorporate climate change into their investment and asset allocation processes, fewer than 10% utilize predictive climate modeling.

> *It is becoming more apparent that physical risks from climate change extend well beyond infrastructure, buildings and other real assets.*

Third, investors can conduct top-down, comprehensive climate scenario stress tests across their entire portfolio. These sweeping climate scenario models are quite elaborate and incorporate policy actions as well as societal responses to them. This complexity leads to a very wide range of results from the stress tests. While the results from these broad climate scenario tests may help provoke internal discussions on the impact of climate change, in most cases they are not granular enough to be easily actionable or guide specific investment decisions.

Despite the current complexity and challenges in translating broad multi-decade climate scenarios into investment decisions, it remains a worthwhile aspiration for the industry, which will only improve as data quality gets better and methodologies and approaches become more standardized. As that happens, climate scenario analysis will increasingly become an important tool for financial regulators aiming to analyze the systemic effects that arise from climate change or CIOs looking to better understand the multidimensional climate risks woven into their portfolios.

As broad climate scenario stress testing becomes more useful for investors in the future, there are several important considerations. For starters, scenario analysis is not a standalone process. It needs to be integrated into investors' governance, risk management and investment processes. This kind of analysis touches upon a broad swath of functions and disciplines within an investor's organization, including the board, investment strategy, reporting and risk management. CIOs need to have a clear plan for coordinating this cross-functional engagement.

In addition, investors need to select a practical set of scenarios from a dizzying array of choices. For investors, optimal scenarios should include both transition and physical risks and focus on pathways as well as outcomes. In this way, investors can consider orderly and disorderly pathways under a diverse set of technology and policy assumptions.

Finally, climate scenarios should stretch beyond the typical investment and analysis horizon, focus on externalities not yet incorporated into the portfolio's value and will likely need to be supported by a comprehensive and transparent climate data strategy and models.

3. Look beyond obvious physical risks to uncover embedded climate risks across the portfolios

It is becoming more apparent that physical risks from climate change extend well beyond infrastructure, buildings and other real assets. These underappreciated, "hidden" risks are in industries not typically associated with climate change exposure (Box 2). Investors don't often think of Swiss pharmaceutical companies and Japanese chip manufacturers as being highly exposed to physical risk from climate change like extreme heat, flooding and drought. Indeed, these exposures are not readily apparent. They lurk far from corporate offices and are embedded within complex global supply chains.

As the coronavirus pandemic has laid bare, supply chains represent key vulnerabilities for manufacturers. Climate change has the potential to unleash the same kind of disruptive impact that reverberates through

Box 2: **Climate Analytics Reveal Material Risks to Unsuspecting Companies and Investors**

Semiconductors

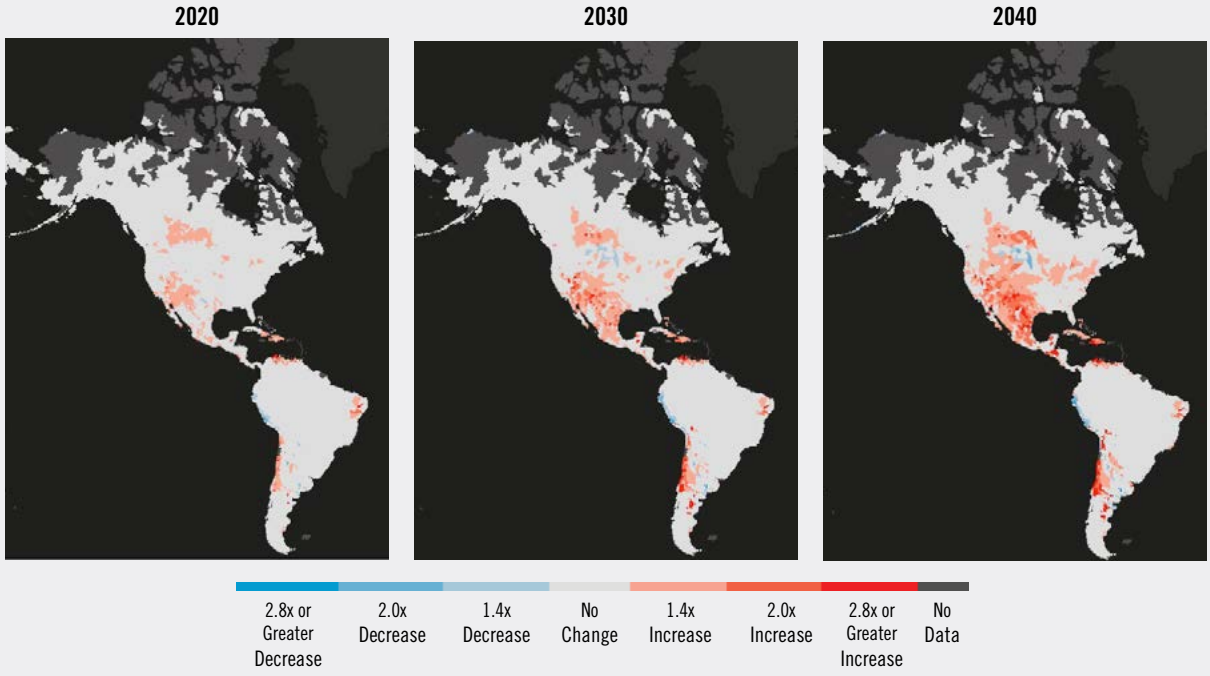
Semiconductors are an essential component of the 21st century economy. The supply chain for the industry is quite geographically dispersed, with major production centers in the US, East Asia and Europe. Importantly, the industry faces an array of climate risks which vary by region and offer illustrative examples of industrywide climate risks that are often overlooked.

Four Twenty Seven analyzed the geolocation of over 2,300 production facilities either owned by or supplying components to the 50 largest chip makers, and overlaid detailed regional maps of locations at high risk for drought, flooding, extreme heat and severe storms. Their research revealed that nearly half of these chip production facilities were exposed to water stress. This represents a critical threat to semiconductor manufacturers who rely on ultrapure water during every step of the manufacturing process.[116] In addition, greater severity and frequency of drought would likely increase the costs of both procuring and purifying water and potentially limit production. Competition with local citizens and businesses for scarce water resources could also adversely impact companies' reputations and hurt their sustainability ratings. Virtually all the companies analyzed were exposed to water stress in at least a quarter of their facilities. Water stress is especially prominent in the southwestern US where almost two-thirds of facilities face this potential climate risk (Exhibit 22).

Investors need to be aware of how companies manage these risks as it can make a material difference in earnings performance. For example, some companies in Asia and the US have developed innovative production techniques that recycle water.[117] Others have invested in conservation projects or partnered with local authorities to develop water treatment facilities.[118] These measures have already paid off for some Taiwanese chip manufacturers whose production was more resilient despite stringent water restrictions during the 2015 drought.[119]

Water stress is not the only climate threat to semiconductor manufacturers. Some chip manufacturers also face considerable risk from typhoons and floods, especially fabrication plants and subcontractor facilities in East Asia, a key region for the industry's supply chain. According to Four Twenty Seven's analysis, two-thirds of East Asian facilities are exposed to elevated risk from strong winds associated

Exhibit 22: **Water Stress Is Forecast to Rise in North America**



Source: Luck, Landis, and Gassert "Aqueduct Water Stress Projections: Decadal Projections of Water Supply and Demand Using CMIP5 GCMs," World Resources Institute, 2015, accessed through prepdata.org in 2020

Note: Water stress is measured by evaluating water demand (withdrawal and consumptive use), water supply, the ratio of water withdrawal to supply, and intra-annual (seasonal) variability for the periods centered on 2020, 2030, and 2040. The baseline is defined as the period between 1950 to 2010. This exhibit captures the business-as-usual scenario.

with typhoons and a third are exposed to flood risk. This risk is not merely hypothetical either. The 2011 floods in Thailand, for example, led to local disruptions in chip manufacturing and triggered global interruptions in the communications and automotive sectors as well. The flood disrupted about 10% of one firm's chip production and was estimated to cost hundreds of millions of dollars in lost revenue and damages.[120]

Pharmaceuticals

Pharmaceutical manufacturers are also especially vulnerable to water stress because purified water is an essential component in their manufacturing process. Based on the analysis of publicly traded pharmaceutical companies conducted by Four Twenty Seven, 85% of companies reviewed are exposed to water stress in at least a quarter of their facilities. For example, exposure to water stress is prevalent across 88% of the production facilities located in India and more than half the facilities in the US.

Additionally, many pharmaceutical drugs and key ingredients can degrade quickly and must be stored at precise temperatures to maintain their efficacy. Episodes of extreme heat can lead to increased energy costs for cooling and lost product should heat waves lead to power outages or other disruptions. More than half the facilities in North America and 95% of those located in Brazil are exposed to heat stress.

supply chains and impacts a wide range of industries. For investors, companies that manage these risks more effectively may build a competitive advantage in their industry and provide more resilient production for customers and revenues for investors. Overlaying the geolocation of key production and supplier facilities with climate data and analytics can reveal which facilities are in high stress regions and which operations are exposed to physical climate risk. This kind of analysis enables investors to assess the latent risk embedded in the value chains of individual firms.

> *New green investment opportunities are emerging to fund climate-related activities of households, firms and governments.*

Even green assets assumed to benefit from climate change mitigation and adaptation efforts face underappreciated climate risk. For example, insurance for solar projects to cover potential damage from hailstorms has become either unavailable or prohibitively expensive. For infrastructure equity holders, this can make it difficult to maintain insurance coverage requirements with their lenders. This can also leave infrastructure debt holders with unexpected risk if their borrowers aren't able to maintain the protections included in the original underwriting. Given that investments in assets such as solar projects are typically held for 10-20 years, infrastructure investors are at particular risk from annual insurance renewals.

4. Monitor emerging climate change-related asset classes for scale, viability and returns

A range of new "green" investment opportunities are emerging to fund climate-related activities and investments by individuals, companies, and governments (Table 3). However, many are at a very early stage and may not currently be at the scale required for institutional investors. It will be important for CIOs to monitor these developing markets as they mature and determine when and if they might become viable investment opportunities for their portfolios.

However, these less mature markets offer sophisticated investors willing to engage with them a unique opportunity. Early institutional investors can shape the market and investment structures for these new climate change-oriented asset classes.

Table 3: **Green Investment Key Facts and Considerations**

	Key Facts	Considerations
Green Bonds	■ **What are they?** Fixed income securities that raise capital for projects believed to have environmental benefits ■ **Sizable market:** Total market size of over $1 trillion[121] ■ **Steady issuance:** 2019 saw issuance of $270 billion and 2020 was on pace to exceed that[122] ■ **Maturing market:** Multiple issuers across the curve enable robust portfolio construction	■ **Few standards are universal or mandatory:** Lack of clear guidelines for what constitutes a green investment has led to instances of "greenwashing"
Carbon Emissions Allowances	■ **What is it?** Rights to carbon emissions that are traded on regulated exchanges in Europe, China and North America – Potential way for investors to offset climate transition risk ■ **Sizable market:** European and American markets have aggregate market value over $50 billion[123] – Emissions trading expanding into China will see volumes grow	■ **Limitations:** Does not hedge against physical risk – Need to access market through specialized managers – Not a truly global market and trading is largely at regional level ■ **Volatile markets:** Market prices can fluctuate greatly according to changes in regulatory regime – Market prices can fluctuate wildly during recession as supply of credits does not adjust lower quickly (e.g., early 2020)
Solar ABS	■ **What is it?** Securities backed by loans made to individuals to finance solar panels for their homes – Loans are repaid in part by a tax credit that comes later as well as savings from lower utility costs	■ **Unusual structure:** Tax credit prepays a portion of the loan which adds complexity and makes it difficult to value for investors ■ **Nascent market:** Issuance reached $2.5 billion in 2020 as demand from investors soared[124] ■ **Poor underwriting:** Concerns that many loans are based on simple FICO scores rather than cash flow or ability to pay ■ **Inconsistent standards:** Limited verification whether solar panels were installed correctly or in the optimal location to generate electricity
Resiliency Bonds	■ **What are they?** Hybrid of insurance and resilience projects to monetize avoided losses or reduced costs through a rebate structure – Attractive objectives and structures for foundations that need to put funds to work annually	■ **Nascent market:** Relatively small market compared to others – Constraint on scaling up may be availability of projects ready to finance

Conclusion

There is no doubt that climate change is and will continue to have profound implications for how long-term institutional investors build and protect their portfolios. Across public and private markets investors must position their investments and overall portfolios for the accelerating climate transformations in our economy and markets. No one can perfectly predict the dynamics of asset price adjustments as climate risks get internalized – or whether the adjustment will be smooth or abrupt – but a repricing will occur, and investors will need to be prepared.

At PGIM, we believe active investors must be on the front foot, predicting and responding to the impact of climate change on the economies and our markets in which investors operate. This will create both immense uncertainty and opportunity. Only forward-looking, long-term investors will have the nimbleness and foresight to seize the opportunities and navigate the risks of our changing climate.

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Nik Steinberg, Managing Director, Head of Research at Four Twenty Seven

Shalini Vajjhala, Founder and CEO at re:focus partners

Sanjay Wagle, Managing Director at the Lightsmith Group

PGIM Contributors

Linda Benedetta Andreoletti, Pramerica SGR
Neil Brown, Jennison Associates
Wendy Carlson, PGIM Private Capital
Florence S. Chan, PGIM Fixed Income
Moya Chew-Lai, Prudential Financial, Inc.
Peter Clark, Jennison Associates
Lisa Cole, PGIM Fixed Income
Susan Courtney, PGIM Fixed Income
John Di Paolo, PGIM Fixed Income
Garrett Falzone, PGIM Fixed Income
Linda Galsim, Jennison Associates
Cathy Hepworth, PGIM Fixed Income
Christy Hill, PGIM Real Estate
Teresa Ho Kim, Jennison Associates
Gary Horbacz, PGIM Fixed Income
Dr. Taimur Hyat, PGIM
Jessica Jin, QMA, a PGIM Company
Ed Keon, QMA, a PGIM Company
Christina Kim, PGIM Private Capital
Suzanne Klatt, Prudential Financial, Inc.
Warren Koontz, Jennison Associates
Joshua Livnat, QMA, a PGIM Company
Bryan McDonnell, PGIM Real Estate
Lee Menifee, PGIM Real Estate
Dr. Katharine Neiss, PGIM Fixed Income
Bill Pappas, PGIM Private Capital
Dr. Harsh Parikh, PGIM Institutional Advisory and Solutions
Giancarlo Perasso, PGIM Fixed Income
Greg Peters, PGIM Fixed Income
John Ploeg, PGIM Fixed Income
Ommeed Sathe, Prudential Financial, Inc.
Jay Saunders, Jennison Associates
Dr. Nathan Sheets, PGIM Fixed Income
Jamie Shen, PGIM Real Estate
Gavin Smith, QMA, a PGIM Company
Aayush Sonthalia, PGIM Fixed Income
Pinto Suri, PGIM Fixed Income
Brian Thomas, PGIM Private Capital
Robert Tipp, PGIM Fixed Income
Dr. Yesim Tokat-Acikel, QMA, a PGIM Company
Eugenia Unanyants-Jackson, PGIM Fixed Income
John Vibert, PGIM Fixed Income
Dr. Noah Weisberger, PGIM Institutional Advisory and Solutions
David Winans, PGIM Fixed Income

Principal Authors

Shehriyar Antia, PGIM Thematic Research
David Klausner, PGIM Thematic Research

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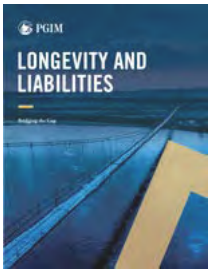

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