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# UNHEDGEABLE RISK: HOW CLIMATE CHANGE SENTIMENT IMPACTS INVESTMENT

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# Unhedgeable Risk: How Climate Change Sentiment Impacts Investment

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## Executive Summary

Short-term shifts in market sentiment induced by the awareness of future as yet unrealized climate risks could lead to economic shocks, causing substantial losses in financial portfolio value within timescales that are relevant to all investors.

Factors, including climate policy, technological change, stranded assets, long-term physical impacts and indirect effects of climate may lead to financial tipping points that investors are not currently prepared for.

This research shows that changing asset allocations among various asset classes and regions, combined with investing in sectors exhibiting low climate risk, can offset approximately half of the negative impacts on financial portfolios brought about by climate change. Climate change thus entails “unhedgeable risk” for investment portfolios.

Action to limit warming to below 2°C is shown to have negative economic and financial impacts over the short-term. However, the benefits of early action lead to significantly higher economic growth rates and returns over the long run, especially when compared to a worst-case scenario absent any climate change mitigation.

Even in the short run, the perception of climate change represents an aggregate risk driver that must be taken into consideration when assessing the performance of asset portfolios. These findings are also consistent with evidence that system-wide action would benefit long-term economic growth prospects.

### Climate science and the motivations

Commissioned by the Cambridge Institute of Sustainability Leadership (CISL) Investment Leaders Group (ILG), this groundbreaking report looks at the economic and financial impacts of climate risk modelled over the next five years in order to identify opportunities for reducing climate-related investment risks through portfolio construction and diversification across different asset classes, regions, and portfolios.

While the most significant physical impacts of climate change will probably be seen in the second half of this century, financial markets could be affected much sooner, driven by the projections of likely future impacts, changing regulations, and shifting market sentiments.

This study employs a unique approach to address these short-term implications of the longer-term climate challenge, in relation to climate risk. The complex analysis presented here is the result of a collaborative effort between three research entities within the University of Cambridge, namely the Cambridge Centre for Risk Studies (CRS), The Centre for Climate Change Mitigation Research (4CMR) and the Cambridge Judge Business School.

Both regulators and financial markets react in light of information about climate change, including major events such as storms, floods and drought, policy decisions, and the success and failure of companies.

While such changes are partly visible in the present, they are likely to accelerate as the physical impacts of climate change become more evident and regular as the science predicts. This will influence financial market behaviours gradually in the first instance (i.e. led by the most informed investors) and then, potentially, in a more disorderly fashion as markets seek to dispose of at-risk assets. While some of the economic losses incurred by investors in this transition can be avoided or hedged through mere reallocation strategies, others require higher level system-intervention in the form of policy or regulatory actions.

Despite the readily available risk information, we cannot model the psycho-social dynamics of financial markets that produce short-termism and herd behaviour; however we can model the physical impacts and consequences for the macroeconomy under different scenarios of climate change mitigation identified by the IPCC climate science. In doing so, our study characterises in detail the multi-faceted impact of climate change on different asset classes and geographies.

### Sentiment scenario development

We adopt an approach that – as far as we are aware – has not been applied to analysis of the financial implications of climate change: stress-testing representative portfolios using economic and market confidence shocks derived from climate change sentiment scenarios.

This study quantifies the potential financial impacts of a shift in market sentiment driven by significant changes in investor and consumer beliefs about the future effects of climate change, modelling the impact of three market sentiment scenarios on four portfolios with different asset allocations.

### Scenario stress-testing

The study investigates how long-term climate risks between now and 2100 may affect the global economy and investment portfolios over the next five years. One scenario looks at how future geophysical impacts brought about by climate change may change economic conditions and investor behaviour. The second scenario looks at the economic and financial effects of a transition to a low carbon economy and what this might mean for the economy and investment decisions. The method applies a scenario stress-testing approach which builds coherent, highly unlikely yet still plausible, quantifiable narratives that describe how expectations about future climate trajectories may impact economic and financial markets over the next five years. The method develops narratives from the latest IPCC climate change projections to understand how these different futures may affect financial markets over the short term. The study also draws on examples from historical financial and economic crisis to interpret and bound model parameters within a climate risk framework.

### Behind the sentiment scenarios

#### Scenario selection

The scenarios reflect differing beliefs about the likelihood of government action to limit warming to 2°C, the actual emission levels anticipated, as well as physical climate change impacts, the probable stringency of regulation and levels of investment, including the types of technology likely to be developed.

These scenarios, aptly named: Two Degrees, No Mitigation, and Baseline, were developed according to well-recognised risk modelling techniques, drawing on the latest IPCC climate change projections and employing analysis of historical market shocks that offer meaningful parallels to interpret and model parameters within a climate risk framework.

#### Extreme, low-probability events

Two Degrees and No Mitigation are treated as unlikely scenarios that have been designed to have a likelihood of occurring of 5% or less. These extreme scenarios represent futures that are in the long-tail distribution of expected global average temperatures.

Baseline represents the most likely outcome estimated in the middle of the distribution of expected future temperatures and represents an increase in global average temperatures of between 2 – 2.5°C by 2100.

### Economic impacts

Each scenario is developed by specifying the magnitude and duration of shocks that are applied to different macroeconomic variables across different regions of the world. The outputs from this model provide detailed information on the quarterly performance of different asset classes (fixed income, equities, commodities etc.) for each of the different countries included in the analysis. This information is then used in a financial portfolio model to determine the overall performance of four comparative portfolio structures, namely, fixed income, conservative, balanced and aggressive. This analysis enables the quantification of impacts for each scenario across different asset classes, industrial sectors, countries and portfolio structures.

#### *More than US\$19 trillion GDP@Risk*

The macroeconomic analysis shows that the transition to a low carbon economy carries increased economic costs in the short-term, but that longer-term discounted benefits make a transition more than worthwhile.

The sheer scale of structural change required for the global economy to shift away from a future dominated by fossil fuels towards a low carbon economy requires tremendous investment in new capital infrastructure, in research and development, and in new business models. This transition period lasting years will be costly to the global economy. However, the alternative may well be worse: results from the macroeconomic analysis show that the No Mitigation scenario triggers a global recession that lasts for three consecutive quarters, shrinking the global economy by as much as 0.1% each quarter. The cost to the global economy is immense estimated at US\$19tn in global economic output over a five-year period (GDP@Risk).

#### *The longer-term economic outlook*

Over the longer time horizon (2015-2050), the Two Degrees scenario is demonstrated to outperform the Baseline by 4.5% with a discount rate of 3.5%. On the other hand, between 2015 and 2050 the No Mitigation scenario costs the economy 14% in aggregate lost output and in 2050 is 25% below baseline output. While the degree of benefit varies by portfolio type, all portfolios experienced short-term losses and long-term benefits.

Clearly, it is only after a period of learning, technological progress and construction of new infrastructure systems that the positive benefits of the new low carbon economy begin to accrue. The Two Degrees scenario contrasts markedly with the No Mitigation scenario where economic output never recovers and is suppressed indefinitely below the Baseline scenario.

### **Financial Impacts**

#### ***53% of portfolio value is unhedgeable from climate change sentiment risk***

The results of this analysis show that, on a worst-case No Mitigation basis, 47% of the negative climate change impact across industry sectors can be hedged through industrial sector diversification and investment in industries that exhibit lower climate-related risks (page 39). Similarly, shifting from an aggressive equity portfolio to another with higher percentage of fixed-income assets makes it possible to hedge 51% of risks associated with equities. However, these two “halves” are not cumulative, such that no strategy will offer more than 50% risk diversification. This gives rise to the conjecture that, even in the short-term, climate change will constitute an aggregate risk that requires system-wide action in order to mitigate its economy-wide effects.

#### ***Implications for portfolio managers and asset owners***

Results show that the High Fixed Income portfolio carries the least risk from financial market disruption, but also experiences low performance across all scenarios. In comparison, under the No Mitigation scenario, a Conservative portfolio with a 40% weighting to equities (typical of a pension fund) could suffer permanent losses of more than 25% within five years after a financial tipping point has been reached. An Aggressive portfolio with 60% equities and more heavily invested in emerging economies could suffer permanent losses of 45% or more. Sectoral analysis shows that some hedging of climate risk is possible by targeting low risk equity investments across different regions and sectors of the economy. In the developed economies those sectors most impacted from climate change are real-estate, basic materials and construction while in the emerging economies these are energy, oil and gas, consumer services and agriculture. Overall, emerging markets are the worst affected. Results from the models suggest that approximately half of the impact on returns attributable to climate change can be hedged through cross-industry and regional investment in low climate risk sectors.

At the multi-asset portfolio level, only half the negative impact of climate change on returns can be hedged by changing asset allocation.

### **Risk management strategies**

Our analysis – alongside data tables generated for all our scenarios – provides investors with guidelines for minimizing their exposure while, at the same time, stimulating a dialogue that goes beyond mere reallocation of resources to build a more sustainable capital market in an economy that is subject to environmental change.

# 1 Introduction

As awareness of climate-related risks grows and gains traction, prudent asset owners and asset managers are beginning to question how global environmental trends – such as increasing pressure on agricultural land, food security, soil degradation, local water stress, and extreme weather events – will affect the macroeconomic performance of countries, and how this will play out in financial markets.

To address these questions, and on behalf of the Investment Leaders Group (ILG), the Cambridge Institute for Sustainable Leadership (CISL) has commissioned this research from three Cambridge institutions: the Centre for Climate Change Mitigation Research (4CMR), Cambridge Judge Business School and the Centre for Risk Studies (CRS) therein. 4CMR has notable capacities in climate change research, whereas the Centre for Risk Studies, located within the Cambridge Judge Business School, has deep expertise in the simulation of financial and economic impacts of various types of risk.

## Investor risk

Climate change poses a major risk to the global economy affecting the wealth and prosperity of all nations. It will have major impacts on the availability of resources, the price of energy, the vulnerability of infrastructure and the valuation of companies. This collaborative report studies how global trends arising from the possible impacts of climate change may lead to a shift in market sentiment over the short term. The study quantifies the economic impacts across regions, industry sectors, and different asset classes, and models the estimated change in value for different portfolios and asset classes. In principle, the financial impacts resulting from different forms of risk exposure can be hedged through strategic asset allocation and portfolio construction. However, some portion of risk exposure remains effectively ‘unhedgeable’ due to the inherent systemic risks associated with different climate change scenarios. Avoiding systemic risks will require system-wide approaches such as climate change mitigation and adaptation measures at the local, regional, national, and global levels.

Appendix A presents a recent collection of articles that have been published over the past decade and were used during this research. These papers represent important market developments in the field of climate change economics ranging from identifying climate change as an emerging risk, to addressing climate

risks in the economy and for portfolio management (Mercer, 2015; Mercer, 2014; Guyatt, 2011; Rogers et al., 2015; Stathers and Zavos, 2015; Kraemer and Negrila, 2014; Committee on Climate Change, 2014; Wellington and Sauer, 2005).

## Study aim and objectives

The most significant geophysical impacts of climate change will most likely be observed in the second half of this century. As the climate continues to warm, global impacts will accumulate over time resulting in higher long-term impact risks, particularly if global average temperatures rise above 3°C (Pachauri et al., 2014). Financial markets, however, could show the impact of risk aggregation much sooner as the effects of climate change will be driven by the projections of likely future impacts, changing regulation, and shifting market sentiment. Therefore, investors should not be deterred from identifying and managing impending climate-based sentiment risks in present-day financial markets based on long-term climate change projections. In fact, investors who act now may benefit from first-mover advantage, or at the very least, minimise their exposure to such risks which could evolve even more rapidly than anticipated. This is possible if climate science advances allow the timing of ‘tipping points’ for climatic instability to be predicted. Even in the case that climate-tipping points could be predicted within some level of confidence it is likely most impacts occurring as a result of the fall-out could not be avoided.

This study models the effect of market behaviour and how financial investment decisions will be made under different climate change sentiment scenarios. Anticipating how the market may respond to long-term climate risks attempts to bridge the gap between the geophysical impacts of climate change over the longer-term and the potential effects that climate risk may have on the economic and financial markets today. The aim in this study is to first identify and then to quantify the financial impacts that may arise from a shift in market sentiment driven by significant changes in investor and consumer beliefs about the future effects of climate change. Given certain conditions about the future effects of climate change are believed and acted upon by a proportion of the financial market, this may create a financial tipping point where investors will be prompted to change their behaviours today to reduce their exposure across different asset classes.

This study intends to shed light on the vulnerability and resilience of different asset portfolios to climate change related risks. With this information, investors will be able to hedge risk and invest in assets with lower potential of being affected by climate risk.

### **Structure of paper**

The paper is structured as follows. Section 2 explains climate change as an emerging risk to asset owners and managers. This section introduces climate science, the economics of climate change, as well as the direct and indirect risks to the economy and financial markets. Section 3 describes the methods and stress testing approach that was used to model a shift in market sentiment. Section 4 illustrates the long-term climate impacts on different industry sectors and regions around the world using zonal climate statistics. Section 5 defines the stress test scenarios and narratives associated with each of the scenarios. Section 6 describes the macroeconomic modelling and main economic results. Section 7 runs the economic modelling outputs through a financial portfolio model, and finally section 8 concludes.



## 2 Climate risk

### The climate science history

Climate change is not a new phenomenon and dates back to the 18th century when Joseph Fourier (1768 – 1830) provided a mathematical proof on the effects of terrestrial and atmospheric radiant heat that drive the so-called greenhouse effect. Building on this early work, Svante Arrhenius (1859 – 1927) showed the importance of atmospheric carbon dioxide (CO<sub>2</sub>) in trapping heat and warming the earth's surface (Labatt and White, 2007, p.3).

Arrhenius was the first scientist to publish estimates on the climate sensitivity metric, which represents the amount of heating that will be caused by a doubling of CO<sub>2</sub> levels in the atmosphere. He predicted that the doubling would cause an increase in global average temperatures of between 1.5 to 5.0°C, an estimate not too dissimilar from recent climate model projections. Since the industrial revolution, the amount of CO<sub>2</sub>-eq in the atmosphere has increased from roughly 280ppm (parts per million) to 400ppm today, representing an increase of approximately 40%. This concentration is the highest in the last 800,000 years and is likely to be the highest level for the last 20 million years. Atmospheric concentrations of CO<sub>2</sub>, methane and nitrous oxide have increased to unprecedented levels driven primarily through fossil fuel emissions and secondly from net landuse change emissions due to human activity. Anthropogenic CO<sub>2</sub> emissions have also been accumulating in the atmosphere, ocean, and terrestrial ecosystems at an increasing rate since the industrial revolution.

The latest climate science as reported by the Working Group I to the IPCC's Fifth Assessment Report (AR5) summarises the following:

*The atmosphere and oceans have warmed, the amount of snow and ice cover have diminished, sea levels have risen, and the concentration of greenhouse gases have increased (Stocker, 2014).*

Since the first publication the IPCC reports in 1990, climate models have improved considerably where the latest models are now able to reproduce observed continental scale surface temperature patterns, rapid warming, and cooling immediately following volcanic eruptions.

The attribution of climate change to human influence has also been detected across many climate systems, making it extremely likely that anthropogenic activities have been the dominant cause of the observed warming since the mid-20th century (Alexander et al., 2013).

### Looking ahead

If left unchecked continued emissions of greenhouse gases will cause further changes in all components of the climate system and lead to warming of between 0.3 – 4.8°C by the end of this century across the range of Representative Concentration Pathway (RCP) scenarios. Global oceans will continue to warm and become increasingly acidic, toxic for all but the most adaptable marine ecosystem. Warming oceans may also affect ocean circulation currents and disrupt weather patterns.

	Scenario	Mid-21st century		End-21st century	
		Mean	Likely Range	Mean	Likely Range
Global Mean Surface Temperature Change (°C)	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
Global Mean Sea Level Rise (m)	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

**Table 1: Projected change in global mean surface air temperature and global mean sea level rise for mid- and end- 21st century relative to the reference period of 1986-2005 (Summary for Policymakers (SPM) of the Working Group I contribution to the IPCC Fifth Assessment Report, (Alexander et al., 2013).)**

It is extremely likely that Polar Arctic sea ice will continue to shrink and thin, thus opening up the Northwest Passage. Under RCP8.5 scenario, it may even become ice-free by the middle of this century. Spring snow cover will decrease as global mean surface temperatures rise. Glaciers across the world will continue to melt, predicted to decrease in volume between 15% and 85% with medium confidence. Global mean sea level will continue to rise and will very likely exceed the rates of increase experienced over the period 1971 – 2010. The rise in sea-levels will most likely be caused by ocean warming and increased loss of mass from glaciers and ice-sheets around the world. The likely range in sea-level rise will be between 0.26 – 0.82m across the different RCP scenarios (Table 1).

### **Opportunities for stabilisation and climate change commitment**

The effects of climate change over the next century are largely determined by the cumulative stock of CO<sub>2</sub> emissions in the atmosphere. Given the capacity of the earth-climate system to reabsorb anthropogenic CO<sub>2</sub> emissions takes a very long time, it is estimated that between 15 – 40% of total emitted CO<sub>2</sub> will remain in the atmosphere for 1,000 years or more (Stocker, 2014). Therefore most aspects of climate change will persist for many centuries to come, even if emissions of CO<sub>2</sub> are stopped and no attempt is made to remove the stock of emissions already in the atmosphere.

### **Climate change adaptation**

Adaptation is the process of managing climate change impacts. While climate change mitigation attempts to prevent the worst impacts of climate change from occurring, climate change adaptation attempts to minimise the worst impacts of climate change through building resilience and reducing impacts after they have occurred. Adaptation, therefore, does have potential to minimise some of the worst effects of climate change.

Wealthy first-world countries will benefit most from adaptation, while poorer developing countries will be the most affected by climate change (Field, 2014). Extreme weather events can have enormously varying impacts for different populations depending on vulnerability and capacity to cope. If done correctly, adaptation measures have the potential to reduce some of the risks that climate change poses to human populations. However, some of these measures, like geoengineering, have unknown and potentially uncertain dangerous side-effects (Heyward, 2013). Geoengineering solutions that block radiant energy from entering the earth do not solve other problems like changes to the terrestrial carbon cycle and ocean acidification.

Other studies have concluded that geoengineering is not a magic bullet and the acceptability of such solutions will be driven as much by social, legal, and political issues as by scientific and technical factors (Shepherd, 2012).

### **The economics of climate change**

It is now unequivocal that climate change is occurring and that human activities are the major contributory factor. Over the last decade there have been significant advances in the ability of climate models to simulate the impacts of CO<sub>2</sub> emissions on the world's ecosystems. As these models have evolved and grown in sophistication the impacts of climate change have become increasingly acute.

In the seminal work by Sir Nicholas Stern (2007), climate change was shown to not only be a scientific concern but also pose a serious economic threat. Stern estimated that unabated climate change could cost the economy between 5 and 20% of annual global GDP if not tackled early. The financial implication of such a large decrease in global productivity is evident. By acting promptly and avoiding the worst impacts, Stern estimated the transition costs could be as low as 1% of GDP. The estimated range in economic costs shows the challenges that investor's face, especially in reducing their risk and exposure to climate risk and alleviate potential losses.

Many economists describe climate change as one of the greatest market failures known to man. The inability of the market to effectively put a price on carbon means there are no incentives for driving a change in behaviour, thus increasing the overall risks brought about by climate change.

Most notably, if climate change continues unabated, it will be future generations who will be burdened with a greater share of these risks. Moreover, the longer we wait to make the transition the higher the potential risks will be.

### **Climate change risks**

Unlike pollution, acid rain or contaminated land, climate change is a global phenomenon and has the potential to affect all companies, industry sectors, and countries across the world. Climate change is therefore one of the most financially significant environmental concerns facing investors today. Complicating matters further, climate risks are not all equal.

Different sectors, regions, and assets will be affected to varying degrees depending on their geographic location, energy intensity, and proximity to climate-induced extremities.

Modelling the differences in impacts across regions, sectors and assets is therefore critical to finding solutions and adopting strategies that can be used to minimise the risks of climate change and reduce aggregate losses.

On the basis of the IPCC results, an increase in temperature of 2°C (~400ppm) above pre-industrial levels is thought to be the maximum 'safe' level that can be reached without causing excessive environmental harm. Although this target has been officially endorsed and scientifically justified, some scientists argue that the 'danger' threshold is actually much lower (Tschakert, 2015). Hansen (2005) argued that a 2°C limit inappropriately accounted for climate sensitivity and climate feedback processes and a 2°C limit already committed the planet to significant warming. Hansen instead advocated for a temperature increase of 1.5°C (~350ppm).

The 2°C limit also fails to protect many of the world's poorest countries and ignores the possibility for tipping points where climate change impacts would be much more severe.

A number of completed research studies identify the types of risks will be amplified by the effects of climate change. While most risks are region-specific, the overall consequences of climate change are negative.

#### *Direct risks*

- Increases in the frequency of extreme weather events
- Increased risk of flooding
- Increased risk of droughts
- Increased risk of water stress
- Increased number of extreme temperature events
- Changes in the distribution and activity of parasites
- Altered agricultural productivity
- Changing fish stocks and migratory patterns
- Disturbance of complex ecological systems
- Loss of biodiversity and extinction of species

Extreme weather events are one of the most prominent impacts of climate change (Bouwer, 2010). The IPCC finds that the frequency of heavy rainfall and heat waves have increased, the areas affected by drought have increased in many regions, and that tropical cyclone activity has increased in the North Atlantic Ocean (Solomon et al., 2007). Unfortunately, the cost of weather extremes are generally omitted or included in a very crude manner (Tol, 2006).

Therefore the cost of extreme weather events is under-represented in most cost-benefit analysis of global climate policies, thereby downplaying the magnitude of potential impacts. The several reasons for this obvious oversight mostly comes down to the uncertainty in estimating the complex interactions that occur between hazards, exposure, and vulnerability (Bergh, 2009).

#### **Indirect risks**

Aside from economic impacts, other indirect risks associated with climate change are often overlooked, but have potential to cause some of the most significant socio-economic disruptions. For example, Risky Business, a report published on the risks of climate change in the US, focuses exclusively on the direct physical effects of climate change and their impacts but ignores the indirect consequences that may result from a changing climate. Most climate change studies focus on impacts that occur within a country's territory, but outside factors make those countries susceptible to the impacts of climate change. The world is highly complex and countries are increasingly interdependent meaning they rely heavily on global markets for access to critical resources. Indirect risks can be broadly classified into four distinct categories (Benzie, 2015):

- **Bio-physical:** transboundary ecosystems such as international river-basins, forests, oceans and the atmosphere may have impacts on other countries. For example, scarce water resources may cause one country to dam a river basin or divert valuable water for irrigation resulting in significant impact on downstream countries and people.
- **Trade:** indirect risks that occur through the trade pathway are transmitted through disruptions across global supply chains. For example extreme weather events in one country may have far reaching effects elsewhere in the globe. One countries response to climate change by introducing new policy to protect national markets or place export restrictions may trigger price shocks and have negative impacts in countries elsewhere around the world.
- **Finance:** indirect risks on financial pathways affect the movement of capital and the exposure of both public and private assets held overseas that suffer lower yields and long-term devaluation as a result of the impacts of climate change.
- **People:** the movement of people across international borders due the effects of climate change represent a growing risk and a potential

humanitarian disaster. Many climate related factors may cause people to migrate, these include: sea-level rise, desertification, decline in tourism trade and human health risks amongst others.

### **The financial and economic risks**

A carbon-constrained future presents a significant challenge for corporations and investors alike. The level of exposure experienced by different companies depends on the geographic location and the sector within which businesses operate. Competitive dynamics are also created by the various climate policies and the possible physical manifestations of climate change (Labatt and White, 2007, p.11). There are four climate risks that impact business, these are: physical risks, regulatory risk, business risk and financial market risk.

#### *Regulatory risk*

A company's exposure to regulatory risk depends on the stringency of GHG policies that are being implemented. The exposure level a company faces from regulatory risk is found on three levels of the company's value chain:

1. Emissions from the company's own operations
2. Indirect emissions from the company's supply chain - especially energy derived from fossil fuels
3. Emissions linked to the use of the company's goods and services

The introduction of climate policies in different regions at different times will mean the impacts of climate policies will have uneven heterogeneous effects. The power sector is particularly vulnerable as fossil fuels remain the primary resource for most power generation companies. Within the power sector there are also significant differences between each firm depending on the age and efficiency of generating assets, the company's share of renewables and its market position. Other sectors like transportation may also see greater efficiency standards or new cleaner technologies start to dominate.

#### *Physical risks*

Physical risks arise from the direct risks of climate change such as droughts, floods, storms and rising sea-levels. The sectors particularly exposed to these risks include agriculture, fisheries, forestry, health care, tourism, water, real-estate, and insurance. Extreme weather events have the potential to cause significant damage to assets and infrastructure, debilitating productive economic activity.

The physical effects of climate change can also have a serious influence on the health and well-being of the population. Extreme temperatures can cause death and illness when experienced for extended periods. There is also increased risk from vector-borne diseases associated with changes in temperature and precipitation patterns. Respiratory-related illnesses and a decrease in life expectancy are also linked to an increase in particulate matter in the atmosphere; a by-product of burning fossil fuels.

Several studies have tried to quantify the potential increased costs that arise from direct physical impacts of climate change. As the attribution of any single event cannot be directly attributed to climate change these methods usually involve the development of stochastic models to predict changes in the frequency and severity of extreme weather events.

One study completed by the Association of British Insurance (2005) concluded that there would be an increase in average annual losses of around \$27 billion a year from three major types of events – U.S. hurricanes, Japanese typhoons, and European windstorms. This represented an increase of two-thirds by 2080 compared to the base-period average. Similarly in a study completed by Coburn et. al (2015) by the Centre for Risk Studies on World City Risk, an increase in the frequency (10%) and severity (5%) of extreme weather events on 300 of the world's major cities placed an additional \$37 billion of global economic output per annum at risk.<sup>1</sup>

#### *Business risk*

At the level of the corporation, business risks include legal risk, reputational risk, and competition based risk. Legal risks occur when litigation attempts are brought against companies for breaching certain climate change responsibilities, breaching a duty of care or causing harm to the individuals or the environment.

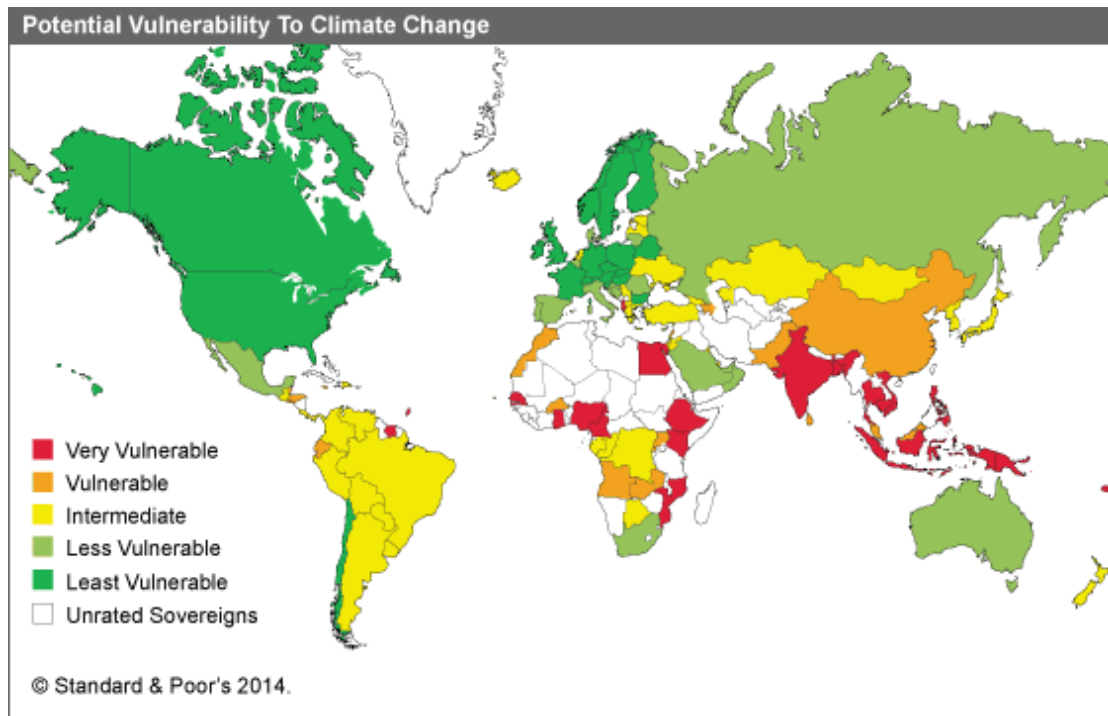
Legal claims can be brought against a company from customers, competitors, investors, or the state. The state itself may face punitive action for failing to meet obligations or being negligent. Reputational risks occur when corporations respond or fail to respond to climate change related matters that alter the perception of brand value to customers, staff, suppliers and investors.

Corporations might suffer a backlash or be viewed in negative light because of decisions that were made with regard to internal carbon management policies, products and processes.

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<sup>1</sup> The study completed by CRS represents aggregate expected losses to GDP from extreme weather events, while the study completed by ABI represents losses to capital infrastructure.





**Figure 1: Geographical representation of potential vulnerability to climate change, figure extracted from Standard and Poor's (2014)**

Reputational risk is particularly important in industries with high brand value, such as the automotive industry and the airline industry where up to 50% of brand value may be at risk.

Risk to a company's competitive position in a market depends on how the company responds to changing regulatory frameworks and other climate related risks. Operational and market based risks may put constraints on existing assets and capital expenditures. Increases in the cost of inputs due to climate policies or supply chain disruption may change the competitive landscape. All of these factors affect the investment valuation of the company.

**Financial market risk**

The performance of individual companies is usually linked to the overall performance of the economy and the level of confidence placed in the financial markets. Large movements and price collapses are usually the first signs that the markets are under stress. Falling prices lead to lower confidence, pushing down prices further. During the chaos of a financial market collapse traders attempt to salvage their investments before prices reach rock-bottom. How might the risk of climate change precipitate such a collapse? Primarily through adjusting prices to the valuation of the companies that will be worst impacted by climate change. For example, agriculture in developing countries and asset owners of climate vulnerable infrastructure will be impacted through changes to the growing season and extreme weather events.

The share price valuation of a company reflects the earning potential of that company into the future, subject to some discount rate. Those companies that would experience the most significant adjustment in price would be those companies that would be most affected by a particular climate change scenario.

**Country credit worthiness**

In 2014 Standard & Poor's carried out an assessment on trends in sovereign risk vulnerability due to climate change. The study concluded that climate change was a global mega-trend that would negatively impact sovereign credit-worthiness. The impact on credit worthiness would be transmitted through several channels including economic growth, external performance and public finances.

As shown in Figure 1 the vulnerability of different countries to climate change is not homogeneous, with the poorer and lower-rated countries affected the most.

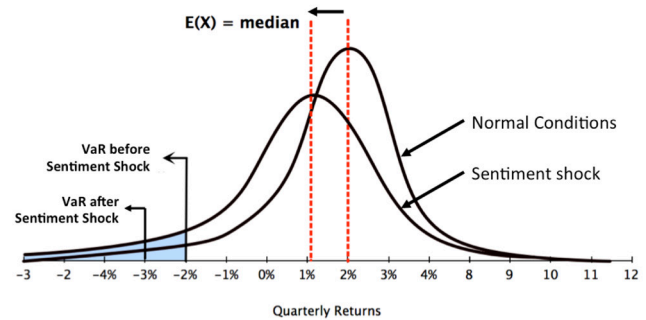
### 3 Modelling and methods

#### Developing a framework for analysis

The aim of an institutional investor is to invest capital in a way that minimises risk and maximises return. Modern portfolio theory (MPT) suggests that investment in diversified assets reduces the overall risk while maintaining a given level of expected return. In this regard, it is not just the expected return of a portfolio that is important to an investment manager, but also the volatility or VaR (Value at Risk) of an investment or portfolio. Large and unexpected negative downturns in specific asset classes over relatively short periods can have serious consequences for investors. One way of reducing portfolio volatility is through diversification of investments. Diversification is helpful when expected returns across different asset classes do not necessarily move in parallel under the same economic conditions.

For example, when external effects are disregarded, bonds and stocks generally move in opposite directions, providing a certain level of protection (i.e. volatility reduction) for the overall portfolio performance. In general, however, the price of different asset classes depends on the underlying performance of the overall economy, so the price of different assets tends to move in the same direction as the economy. This aspect of risk is called ‘systematic risk’ and cannot be diversified away. Unsystematic risk is risk that can be reduced through diversification. An investor who owns stocks in different companies and sectors as well as other types of securities such as treasury bonds will be able to reduce risks when impacts are isolated to particular industries or investment types.

As shown in Figure 2, the shape of the distribution of portfolio returns before and after a climate sentiment shock is important for understanding and estimating the risk to an investment portfolio. Climate change is expected to have a large impact on the expected or average returns of a portfolio, this is shown by a shift in the expected value of quarterly returns, shown as a shift from 2% to 1% in the hypothetical quarterly returns shown in Figure 2. However, under the conditions of a change in market sentiment, the distribution of returns is also expected to change because there will be an increase in the volatility associated with increased uncertainty. This is captured through the fattening of the tails in the distribution of returns. The potential losses of a portfolio in the tail of a distribution is generally referred to as the ‘Value at Risk’ (VaR).



**Figure 2: Hypothetical example of the expected loss versus the Value at Risk for a typical portfolio under normal conditions compared to a sentiment shock**

The VaR of a portfolio therefore represents the losses that would be experienced over a given time horizon with a probability of occurring of 5%. As shown in Figure 2 the VaR of the hypothetical portfolio increases from a quarterly loss of -2% to a quarterly loss of -3% signalling the risk of losses has increased.

The analysis of this report is based on the premise that climate change will cause both systematic and unsystematic risk to investment portfolios. Systematic risk occurs when the effects of climate change and any policies to combat its impacts will cause a structural shift in the overall macro environment of the economy or market (e.g. the global economy degrades).

As the macro environment adjusts to new beliefs about future output, risk is systematically created and adjusted across the entire economy, affecting energy prices, national income, health and agriculture among others. Unsystematic risk occurs when there is additional risk to specific assets or securities that can be explained above and beyond general movements in the underlying economy.

For example, the returns on equity investments are determined by a company’s underlying financial performance, profitability and future return on invested capital. Stock returns are also affected by the performance of the industry as a whole. Under a scenario of extreme climate change, economic performance across the board will be impacted, lowering expectations about the future and reducing overall growth. However, some parts of the economy will be impacted worse than others. For example, real estate in developed countries will experience more volatility in price levels as an increasing number of properties will be at risk of flooding. Thus it is possible to reduce overall portfolio risk by divesting from assets that perform worse and have higher volatility.

A primary question of this research project therefore asks:

*What proportion of climate sentiment risk can be diversified or hedged through portfolio structure and how much climate risk is systematic and therefore linked to macro scale market and economic conditions?*

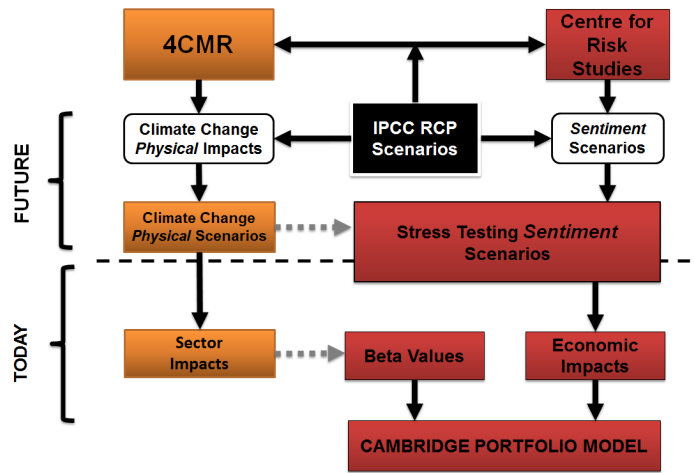
**Modelling timeframe**

The emphasis on short-termism in the financial markets is well where there is an excessive focus on speculative short-term results potentially at the expense of long-term value creation recognised (Dallas, 2011; Bolton et al., 2006). In the current context, together with consultation with our advisory panel of experts<sup>1</sup>, this study concentrates on sentiment scenarios that have immediate financial effects and corresponding actions by prudent rational investors and asset managers over the next five years (i.e. 2016 to 2020). These sentiment shifts and consequential market impacts are years, or perhaps decades, in advance of the more severe climate change impacts. This analysis, therefore, does not attempt to estimate the physical impacts of climate change over this short time-frame, but instead asks how investors today may react to growing certainty over the potential future effects of different climate change trajectories. The analysis therefore considers how present day markets may react to the discounted future impacts of climate change across different countries, industry sectors, and asset classes. Under an extreme climate change scenario, vulnerable assets that are expected to provide a return on investment over the medium to long-term are expected to de-value which would then have much wider effects on market sentiment. A change in overall market sentiment then drags down the entire economy – over the short-term – as prospects about future economic conditions and output are re-evaluated.

**Modelling process**

In order to understand and model the future impacts of climate change on present day financial markets a new modelling approach was co-developed between 4CMR and the Centre for Risk Studies, illustrated by the flow chart in Figure 3.

<sup>1</sup> The members of the advisory panel are: Rob Lake (Independent Advisor), Richard Lewney (MD, Cambridge Econometrics), Dr Mike Maran (Chief Science Officer, XL Catlin), Rick Stathers (Head of Responsible Investment, Schroders), Raj Thanotheram (RI consultant), John Ward (Director, Vived Economics), Michael Sheren (Senior Advisor, PRA Bank of England) and Tomi Nummela (Head of Implementation Support, Principles for Responsible Investment)



**Figure 3: Conceptual links between 4CMR and CRS in the co-development structural modelling methodology framework**

The future climate change regional physical impacts referred to in the RCP scenarios by 4CMR do not directly measure the sentiment shocks in the stress-testing scenarios, but provide CRS with a direction and magnitudes for applying shocks to sectors in the beta analysis modelling. The process followed a number of steps as described below:

*Step One – development of climate change scenarios*

The process begins with identification and development of three climate change sentiment scenarios. These scenarios describe how different climate futures may unfold over time. They include assumptions about technology, policy and socio-demographics, and are based on the existing RCPs, shared socio-economic pathways (SSPs), and shared climate policy assumptions (SPAs). Terminologies are further detailed in Section 5: Defining the Scenarios. Two of these scenarios were chosen to represent futures that lie within the tails of the distribution of all possible climate futures and were therefore targeted to have a probability of occurring of around 5%.

These scenarios therefore represent two opposing futures, one in which the rise in average world temperatures remains below Two Degrees Celsius out to 2100 and the other where there is No Mitigation and the average global temperature rises by four or more degrees by 2100. Note that there is large uncertainty in estimating the probability of any particular scenario occurring, and this uncertainty is only amplified when speculating on the likelihood of a corresponding sentiment shift. It does, however, illustrate the important point, that the scenarios being modelled are not ‘likely’ or ‘best guesses’ but illustrative of the potential tail risk created by climate change.

### ***Step Two – sectoral impacts from future climate change***

The second step involves the synthesis of existing research on the future impacts of climate change under different climate change scenarios. For each climate change RCP scenario the impacts across different countries and sectors are determined. This information is used to inform an analysis of how present day market participants might react to different climate change scenarios as they unfold over the short-term.

### ***Step Three – development of sentiment scenarios***

Outputs from Step One and Step Two are used as inputs into the further refinement of each of the sentiment scenarios. This process takes impacts that occur in the future and translates them into how financial markets may react today. This involves a consequential analysis of how financial markets over the next five years will react to the perceived future impacts of climate change across regions, sectors and asset classes.

### ***Step Four – macroeconomic modelling***

Qualitative and quantitative data from each previous step was then used to determine the relative size of macroeconomic shocks that would be applied to the Oxford Economics' General Equilibrium Model (GEM). The size of the shocks applied to different macroeconomic variables is calibrated, using the historical catalogue, to provide a plausible set of shocks in each scenario. Sensitivity analysis is then performed on each of the shocked economic variables to understand its effect on overall results; this is an iterative process to hone the variables and magnitude of shocks applied.

### ***Step Five – calculation of beta values for sectoral impacts***

One of the outputs of the Oxford Economics' GEM is an equity index for each country being analysed. Historical beta values, derived from a standard CAPM model, are used to describe sector level performance with respect to the underlying equity index for each country. Historical beta values for each industrial sector are then adjusted by the expected shock that would be experienced under each climate change scenario. This has the effect of increasing sectoral volatility with respect to the underlying equity index which is assumed to adjust to this new climate equilibrium level over a period of five years.

For example, if the beta value for agriculture was  $\beta=1.3$  and we shock the beta value by the inverse of the expected shock derived from the climate science models (e.g., agriculture output will decrease by 20%).

When it is assumed that financial markets incorporate the long-term performance of sectors this has a direct effect on sectoral volatility proportional to the long-term effects of climate change. Thus in this instance the beta value would increase from 1.3 to 1.63, indicating increased volatility and uncertainty in the agriculture sector performance. As beta values are representative of the performance of a sector compared to the underlying index, when the equity index performs poorly a sector with a high beta value will perform even more poorly under an economic sentiment shock.

### ***Step Six – portfolio analysis***

The relative performance of fixed income, equities and commodities for each country is provided as an output from Oxford Economics' GEM. These are used to describe quarterly shifts in mark-to-market values over a five year period in a financial portfolio model. Four financial portfolios are constructed: High Fixed Income, Conservative, Balanced, and Aggressive. Each portfolio makes different assumptions about the relative proportion of assets that are invested in different asset classes and regions. These portfolios form the basis of determining how much risk can be hedged under different climate change scenarios.

### **Description of scenario stress-testing analysis**

The practice of using stress tests to check the health of banks and economic institutions has earned increasing popularity in the wake of the 2008 Great Financial Crisis. This study designs a new suite of coherent stress tests to reflect how a sentiment shock may impact the economic and financial markets in advance of the physical impacts of climate change. The scenario stress-testing approach, defined to conduct rigorous what-if analysis, looks at the implications of key economic risks and policy changes following the expected climate risks being studied. The approach seeks to illustrate the impacts of three different climate change scenarios defined by the international science community as 'bracketing' the range of possible climate impacts, and how these scenarios may have an impact on present day markets.

The choice of scenarios, to follow, and the calibration of their impacts are informed by established research in climate science, macroeconomic modelling and financial modelling. More generally, catastrophe types can be identified in advance on the basis of historical records (e.g. the Cambridge taxonomy of macro-catastrophe threats) provides a check-list of potential causes of future shocks (Coburn et al., 2014a) or drawing on perspectives of experts on the most significant long-term risks (World Economic Forum, 2015).



### Complex risks and macroeconomic impacts

These climatic threats are of interest because they are complex risks – they impact networks of activities that underpin the global economy, disrupt interrelationships that drive business, and cause losses in unexpected ways. They have multiple consequences, in causing severe direct losses, but also operational challenges to business continuity, cascades of effects on counterparties and the macroeconomy in general, and on the capital markets and investment portfolios.

However, the exact timing of climate change impacts transforming into economic and financial risks remains highly uncertain, making the threats even more difficult to quantify and prepare for, potentially making them more harmful. In the three sentiment scenarios presented in this report, we explore how these effects might occur, tracing the flow of consequences from initial losses to macroeconomic impacts, and then to financial market effects in terms of portfolio returns.

### Developing coherent scenarios

It is important to identify the capacity and capability for these scenarios to trigger various cascading consequences that are the main causes of any catastrophic loss. These consequences are intertwined into complex risks. For stress tests to be useful, they need to be coherent (i.e., all described effects are consistent amongst one another and they follow a logical sequence relying on causal mechanisms, and represent meaningful correlations across multiple dimensions of impacts). The development of a coherent scenario requires structural modelling, a scientific consideration of the causality along the chain of cause and effect, and a holistic appreciation for the internal consistency within the scenario.

### A structural modelling methodology

To develop a coherent stress-test, we have formulated a methodology to guide the general processes to understand our scenario consequences, summarised in Figure 3.<sup>2</sup> This guide involves sequential processing of the scenario, from defining the scenarios aligned to the appropriate assumptions, to several stages of modelling iterations to obtain results for the economic and financial impacts analyses. The construction of a scenario using structural modelling techniques

<sup>2</sup> Methodology makes references the Cambridge Centre for Risk Studies' four main threat scenarios: China-Japan Geopolitical Conflict (Bowman et al., 2014b), São Paulo Virus Pandemic (Coburn et al., 2014b), Millennial Uprising Social Unrest (Bowman et al., 2014a), and the Sybil Logic Bomb Cyber Catastrophe (Ruffle et al., 2014).

presents various challenges before the requirements for a coherent stress-test can be fulfilled.

One of the key challenges of stress testing is to take an unlikely scenario and make it plausible and coherent. We have attempted to do this through using evidence-based precedents of similar case studies (since the extreme events we are modelling have not yet occurred in today's world), as well as detailed analysis of how similar past events would play out today, under the assumed conditions under which the stress test is applied.

Another key challenge is insuring that these stress-tests can meet the criteria of being useable by businesses, investment managers, or policy-makers for use in risk management. We have therefore worked with key users including an Advisory Panel of experts in responsible investment, risk modelling experts and economic consultants to shape the scenarios so as to meet the management needs for stress testing. We also undertake an extensive review process where the assumptions of the scenarios are tested refined.

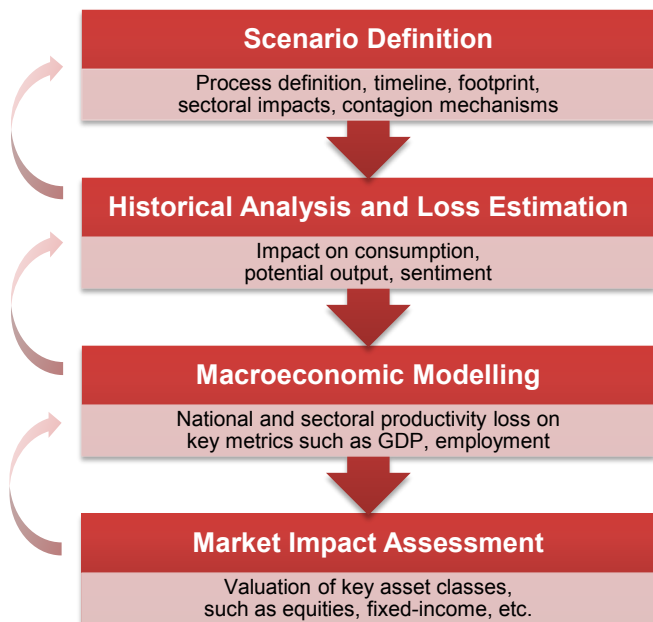
We believe it is important to create a robust and transparent process, and have attempted to achieve this through detailed process of the recorded assumptions, described in the following sections of this report, and sensitivity tests about the relative importance of one input parameter having an impact on another.

In the macroeconomic stages of the modelling, we are conscious that the calibrated macroeconomic models are pushed beyond the comfort zone of normal economic behaviour for use in the modelling of extreme events. Thus, in working with an existing macroeconomic model we have relied on economic model experts to understand the useful limits of the model and identify the boundaries of the models functionality.

### Assumptions and limitations

The economic estimates presented in this analysis are subject to the assumptions imposed during the narrative development and how the scenario unfolds over time. The modelling and analysis completed are also subject to several sources of uncertainty.

A best attempt has been made to ensure the macroeconomic interpretation of the narrative is justified on historical grounds and follows sound macroeconomic theory and principles. However, the unusual and unprecedented nature of these particular scenarios introduces complexity and uncertainty in final model outputs that cannot be completely ruled out.



**Figure 4: The CRS structural modelling methodology to develop coherent stress test scenario**

### **Macroeconomic assumptions**

Several assumptions have been made regarding how sentiment shifts could play out. Firstly, the trigger for these scenarios originates from a collapse in the level of confidence due to the uncertainties accompanying the expected future impacts of climate change, and climate change related policy.

The fall-out from a decline in confidence and the initial shock sends tremors through financial markets around the globe. This shock travels through linkages between asset classes as well as cross-border financial integration and trade relationships. Moreover, the on-going recovery of the economy hinges on how quickly financial markets and consumers regain confidence in the economy.

In the Two Degrees scenario, the impacts are less severe and the markets recover faster compared to the No Mitigation scenario. This is understandable given the positive outlook of well-coordinated global actions towards climate change (i.e. policy certainty) and renewed hope in new technologies and future opportunity. Moreover, the uncertainty of the future impacts of climate change are alleviated as in the Two Degrees scenario the worst effects are avoided.

The magnitude and duration of each macroeconomic shocks are summarised in Section 6, Table 6.

## 4 Climate change impacts

### Background

The severity of the impacts of climate change depends strongly on the degree of change experienced, but also on the level of vulnerability of a region and/or economic sector. Both exposure and vulnerability vary across spatial scales, creating a need to explore the geography of climate impacts on key sectors. While it may be possible to hedge some risk by limiting exposure of assets, other risks will require system-wide actions, both to mitigate climate change impacts and to reduce vulnerability.

### Zonal climate statistics

Weather describes the atmospheric conditions at a specific place at a specific point in time. Such forecasts depend critically on the initial state of the atmosphere, and tend to be accurate for up to one week. Climate models, however, are not predicting day-to-day weather systems. Instead, they take a longer-term view, predicting expected atmospheric behaviours for a given location over a longer period of time. As such, it is not plausible to use climate models to answer specific questions about the occurrence of a particular weather event at a given point in the future. However, they can be used to calculate aggregated weather statistics over periods of 30 years, i.e. climate statistics such as the frequency with which large storms might occur.

There are many types of model and techniques that can be applied to generating projections of future climate change, with different benefits and limitations. The climate model output used in this research was the Atmosphere Ocean General Circulation Models (AOGCMs) and is generated for the Coupled Model Inter-comparison Project Phase 5 (CMIP5). The database was obtained online from the Royal Netherlands Meteorological Institute (KNMI).

AOGCMs are highly complex in their representation of environmental processes, but as they simulate global climate, there are limits to the spatial resolution they can reach. Fine-scale variations in land cover, albedo, soil moisture, among others, have an effect on local climate that these models cannot resolve. Downscaling methods (dynamical or statistical) can be applied if information about variability is required on such a fine-scale (e.g. Duliere et al., 2011); however, as the goal of this research is to aggregate climate statistics over large regions for which sectoral impact information is available, such a level of detail in climate simulations is not required.

Different climate models produce different results when forced with the same RCP scenario. Therefore, the multi-model mean of the CMIP5 experiments is used to aggregate impact estimates.

However, it should be noted that multi-model ensembles are not a systematic sampling of the uncertainty space of future climate, and issues such as model dependence and bias complicate their interpretation (Foley et al., 2013; Knutti et al., 2009; Tebaldi and Knutti, 2007). Using the KNMI database, monthly average near-surface air temperature for each RCP is averaged over the year. A MATLAB script is then used to calculate the mean annual temperature over the end-of-century and baseline periods, and obtain the difference between them.

This anomaly field is exported to ArcGIS, where the zonal mean temperature anomaly is calculated, based on the regions used to generate the damage functions for climate impacts. Representative results of projected climate change are given in Figure 3, using temperature increase (relative to the pre-industrial mean global temperature) as the climate variable.

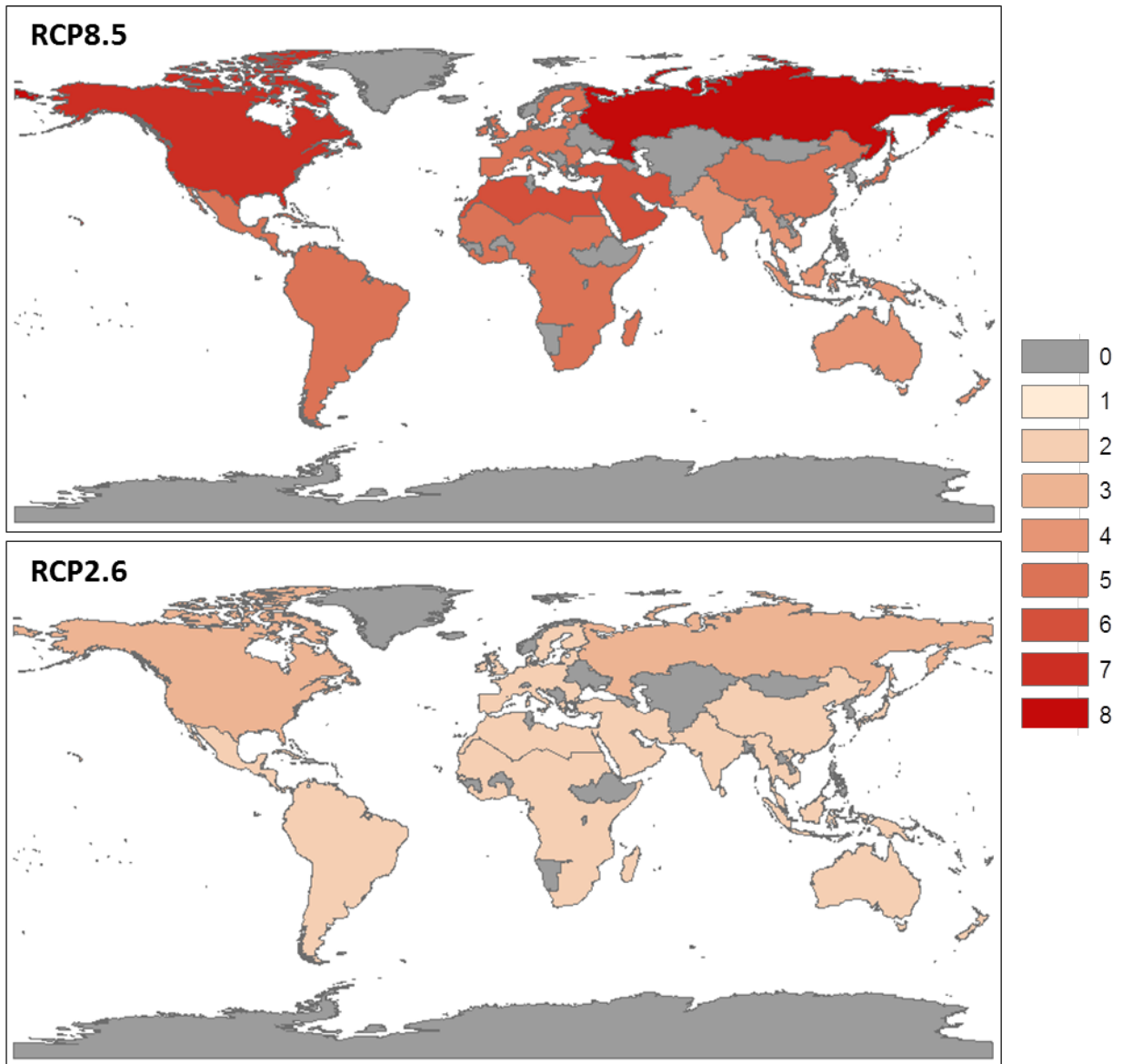
### Derivation of impacts and risks

The impacts of climate change on assets and production capacity in economies have been estimated using a combination of an emulator model of the climate to produce climate projections similar to those of the more complex models used in the IPCC analyses (reducing the amount of computation needed in the present study) and a set of 'impact factors' for different categories of assets and production capacity.

The climate model is used to estimate the amount of temperature and/or precipitation (rainfall) change by year under each climate scenario and in each region of the world, while the 'impact factors' show the amount of damage expected in each asset/production category under this amount of climate change.

The 'impact factors' have been taken from a review of the climate damage estimates in the latest IPCC report, specifically the Synthesis report which draws on the analyses performed by the different IPCC groups on the science of climate change, its impacts and potential mitigation options, with emphasis on the report concerning impacts.

It should be noted that the IPCC analyses of impacts are drawn both from specific assessments in countries, and from regional assessments.



**Figure 5: Regional mean temperature anomalies under RCP8.5 and RCP2.6, for the period 2071-2100 relative to the pre-industrial period. The colour scale refers to the incremental temperature increase (in degrees C) relative to the pre-industrial period temperature.**

They do not result from detailed analyses and hence should be seen as averages of vulnerability across wide geographic areas rather than applying to a specific asset or production capacity. They should, however, represent best available scientific estimates of vulnerability to potential damages from climate change under the climate scenarios considered, based on current (2015) locations of assets and production capacity. In other words, they do not reflect potential shifts in the locations of assets and production capacity globally, since those shifts will be determined by investment decisions.

Representative results of projected climate change – taken from the climate model mentioned – are given in Figure 4, using temperature increase (relative to the pre-industrial mean global temperature) as the climate variable.

The impact factors were developed for 10 regions of the world based on qualitative analyses of the regional results of the IPCC reports. These regions are:

- North America
- Central America
- South America
- Sub-Saharan Africa
- Middle East
- European Union
- Southeast Asia
- China
- Russia
- Australia/New Zealand.



Agricultural productivity								
Temperature change (°C) relative to pre-industrial baseline								
	0	0.5	1	2	3	4	5	6
Region								
North America	1	1.05	1.00	0.95	0.85	0.70	0.60	0.40
Central America	1	1.04	1.02	0.98	0.80	0.70	0.58	0.42
South America	1	1.03	1.01	0.97	0.79	0.69	0.57	0.41
Sub-Saharan Africa	1	1.06	1.01	0.96	0.86	0.71	0.61	0.41
Middle East	1	1.04	0.99	0.94	0.84	0.69	0.59	0.39
European Union	1	1.03	0.98	0.93	0.83	0.68	0.58	0.42
Southeast Asia	1	1.06	1.01	0.96	0.88	0.72	0.61	0.40
China	1	1.06	1.01	0.96	0.88	0.72	0.61	0.40
Russia	1	1.10	1.05	1.00	0.90	0.75	0.65	0.45
Australia and NZ	1	1.04	1.02	0.97	0.78	0.72	0.60	0.44

**Table 2: Remaining production capacity in the Agriculture Sector following any amount of temperature increase relative to pre-industrial revolution, for each of the world regions considered here**

Bearing in mind that these impacts are aggregated over very large regions, and hence variability of climate impacts expected across a particular region is generally 'hidden', and differences averaged out. Hence, the climate results presented here should only be used to compare average, relative impacts across regions of the world, in terms of locations of assets and production capacity.

For each region, damage was assessed for six sectors of the economy: Agriculture, Forestry, Land Transport, Building, Production and Energy. These impacts should also be seen as averages over the region within a category. These impacts are then used in the development of the climate sentiment scenarios that describe how different sectors and regions of the world will be impacted under different climate change scenarios.

An example of the impact to sectoral productivity is described in Table 2, which is expressed as the remaining production fraction after damage to agricultural assets as a result of the change in temperature in that region.

For example, the production value for North America, under an average temperature increase of 3°C is 0.85 (i.e. an approximate decline of 15% in production capacity, in the absent of any adaptation measures).

Table 15 above reflects the respective regions' exposure to changes in temperature and rainfall levels across different sectors.

However, exposure alone does not result in higher climate risks. Resiliency provides another layer of understanding on how countries manage in the changing climate facing many uncertainties and challenges. Thus, subjected to varying degrees of climate risks, the six countries included in the study have different characteristics of resiliency listed below:

- **Preparedness.** Resilience involves the capacity to absorb the shock and then recover from the catastrophic event. Countries can do so by developing physical, economic, human, and/or social capital.
- **Adaptability.** In a changing world constantly evolving, countries that are able and willing to adapt to new conditions are relatively more resilient.
- **Experience.** Either by learning from home countries' experiences or studying the lessons of others in a former manner in handling impacts of climate change, the experiences gained better prepare and adapt the country in the face of climate risks.
- **Collective and coordinated response – interdependency.** Well-coordinate and shared community values are better able and willing to plan for and react to disruptive climate impacts.

Region	Sectoral Productivity (1 = 100%)					
	Agriculture	Forest	Land Transport	Building Assets	Production Assets	Energy
North America	0.62	0.72	0.91	0.93	0.91	0.84
European Union	0.59	0.69	0.90	0.92	0.90	0.81
Central America	0.64	0.75	0.95	0.97	0.95	0.87
South America	0.63	0.74	0.95	0.97	0.95	0.86
Sub-Saharan Africa	0.65	0.75	0.94	0.96	0.94	0.87
Middle East	0.65	0.76	0.97	0.99	0.97	0.88
Southeast Asia	0.68	0.80	0.90	0.94	0.92	0.93
China	0.68	0.80	0.90	0.94	0.92	0.93
Russia	0.71	0.82	0.90	0.94	0.92	0.96

**Table 3: Summary of damage ratios as the combined effects of temperature and SPEI<sup>1</sup> estimated from the climate model across defined sectors for a temperature increase of 4oC between 2080 – 2110.**

<sup>1</sup> Standardised Precipitation and Evapotranspiration Index (SPEI).

## 5 Defining the scenarios

### Defining a climate risk sentiment scenario

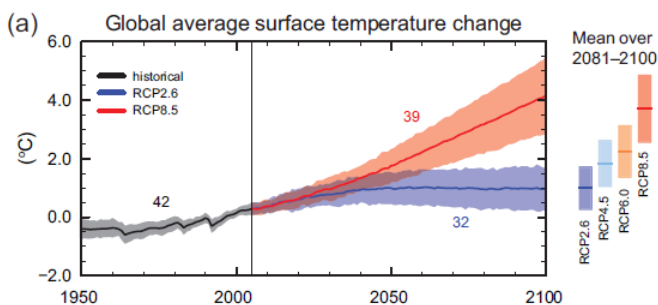
We define a climate risk sentiment scenarios as a shift in market behaviour driven by beliefs about future economic and financial outcomes brought about by the physical processes of climate change, technology and climate change policy. Although the focus on the systemic aspects of climate risks looks at the impacts on a global scale, it is equally important to analyse impacts to individual countries, asset classes, or industry sectors for ‘hedgeable’ risk management.

### Selection process

To select extreme yet plausible scenarios, CRS referenced the scenario matrix architecture and modified it according to our research specifications (see Table 5) (van Vuuren et al., 2013). The potential outcome of climate change depends on three main factors:

- Amount of radiative forcing levels (W/m<sup>2</sup>), given as the RCPs in the IPCC analyses (Figure 5)
- Shared socio-economic pathways<sup>1</sup> (SSPs)
- Shared climate policy assumptions<sup>2</sup> (SPAs)

Figure 5 shows the expected range in estimates for each of the RCP scenarios as given by the IPCC and also represents the range of scenarios chosen for this analysis.



**Figure 6: RCP Scenarios defined by the IPCC** (Source: (Stocker, 2014))

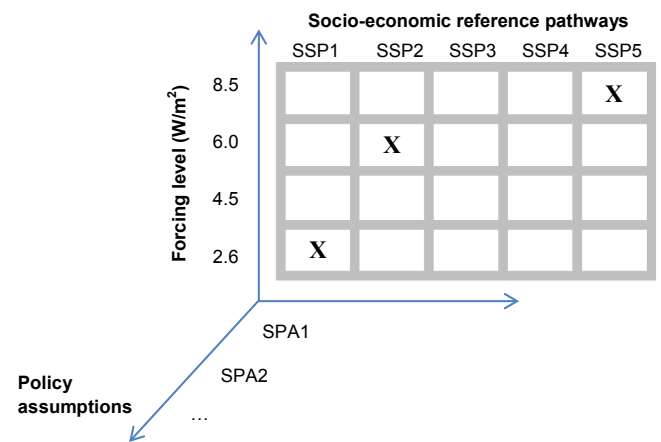
Table 4 below presents a two-dimensional matrix that extracts the specific RCPs with the corresponding SSPs, alongside the SPAs that are defined consistently with the mitigation challenges.

<sup>1</sup> Shared Socio Economic Pathways (SSPs) describe the social and economic assumptions for each country that underpin each of the RCPs

<sup>2</sup> Shared Policy Assumptions (SPAs) are the regulations and agreements for different countries that underpin different RCP scenarios (e.g., carbon tax)

The overview table illustrates many alternative future pathways are possible under different assumptions combining SSPs and SPAs to reach different levels of RCPs in the future. Through implementing different climate policies (SPAs) it is possible to shift the forcing levels from one cell to another (depicted by the ‘X’s and dotted arrows in Table 3). This further shows that there is no one fixed set of climate policies for each socio-economic pathway (SSP). Therefore, the narrative will remain coherent as long as the overall pathway definitions and climate policy assumptions are broadly consistent.<sup>3</sup>

Climate policy assumptions are not, by definition, included as part of the SSPs (O’Neill et al., 2013). In Figure 6, the traditional scenario matrix is therefore expanded to include a third dimension that incorporates climate-signals in a policy-context.



**Figure 7: Extended three-dimensional scenario matrix approach** (Adapted from (van Vuuren et al., 2013))

SPAs usually provide information about new climate policies that are excluded from most socio-economic pathways (Kriegler et al., 2014). In essence, non-climate policies belonging to the traditional pathways are mostly that of development (i.e. economic growth, improving energy access, urban planning, infrastructure, health services, population, and education). They are motivated in their own right, although they may affect climate policies or be affected by them. On the other hand, climate policies would not be implemented if there were no concern about climate change. Examples include policy that directly restricts or taxes the emissions of GHG, or supports technologies that remove or reduce GHG.

<sup>3</sup> Note that in the present analysis, as described in Section 3, RCP2.6 has been paired with SSP1; RCP 6.0 has been paired with SSP2; and RCP8.5 has been paired with SSP5.

**Table 4: The extended scenario matrix architecture** (Source: Cambridge Centre for Risk Studies)

Shared Socio-economic Pathways (SSPs)		SSP1	SSP2	SSP3	SSP4	SSP5
		Sustainability	Middle-of-the-road	Fragmentation	Inequality	Conventional Development
Forcing levels (W/m <sup>2</sup> )	8.5					X
	6.0		X	X	X	X
	4.5	X	X	X	X	X
	2.6	X	X	X	X	X
Example development (non-climate) policy	Economic	High	High	Slow; unequal	Slow; unequal	Very high
	Population	Low	Medium	High	Low to Medium	Low
	Urbanization	High	Medium	Medium	Low	High
	Education	High	Medium	Low	Unequal (very low to medium)	High
Shared climate Policy Assumptions (SPAs)		SPA1	SPA2	SPA3	SPA4	SPA5
Policy attributes	Mitigation: Level and start of global cooperation	High and early	Medium and mid-term	Low and late	High and early	Low and late
	Adaptation: Ability for capacity building	High	Medium	Low	Low	High
Example climate policy	Resource and Energy demand	Low	Medium (reducing)	High	Regionally differentiated (rich-poor divide)	High
	Carbon-based fuel demand	Low	Medium (reducing)	High	Regionally differentiated (rich-poor divide)	High
	Alternative energy Technology	High	Medium (increasing)	Low	Regionally differentiated (rich-poor divide)	Low
		High	Medium (limited)	Low	Low	Low

**The sentiment scenarios**

We use a triplet of (i) selected radiative forcing levels, (ii) socio-economic pathways and (iii) climate policy assumptions to develop three different sentiment scenarios, namely Two Degrees (page 23), Baseline (page 24) and No Mitigation (page 24).

The fundamental assumption in developing these scenarios lies in the public expectations and economic

sentiments to provide a bridge from the future geophysical impacts from climate change to have an effect on the markets today.

Further, these scenarios do not model feedback changes in the evolution and dynamics of policy implementation as each scenario unfolds over time. Rather, we assume the markets behave in a way that is consistent with each future scenario becoming true.



In sociology, this is referred to as the principle of reflexivity, or the more commonly referred to a 'self-fulfilling prophecy', and occurs when the observations or actions of observers in the social system affect the very system they are observing. We remove this contradiction by looking only at the behaviour of the markets under a specific condition: markets believe a particular future scenario is going to come true. In this way the present day reactions of the market are consistent with the belief of each future scenario unfolding and therefore we assume that that scenario will come true no matter what actions are taken to avoid it.

For example, the No Mitigation scenario narrates the market reactions are consistent with the belief that there will be no mitigation and therefore the impacts of climate change will be substantial. As a consequence we do not account for the fact that under the No Mitigation scenario there will be a higher chance that governments will react more strongly introduce new policies and hence avoid the worst effects of climate change.

## Two Degrees

Two Degrees describes a world collectively making relatively good progress towards sustainability, with sustained efforts to achieve future socio-economic development goals. In this analysis, it is defined as being similar to RCP2.6 and SSP1 from the IPCC AR5. Resource intensity and dependence on fossil fuels are markedly reduced. There is rapid technological development (i.e. clean energy technologies and yield-enhancing technologies for land), reduction of inequality both globally and within countries, and a high level of awareness regarding environmental degradation. The world believes that global warming will be limited below 2°C above pre-industrial temperatures, but not without significant expense.

With this expectation in mind, the economy gears up to make a transition away from fossil-fuels and towards a low-carbon economy. However, a shift in long-term investment decisions from several key technology and financial institutions causes volatility and uncertainty in the financial markets leading to a short period of turmoil and lower growth rates. The economy goes through an arduous period of divestment away from fossil fuels, where nearly half of coal and oil assets will become stranded (HSBC, 2013).

As the economy successfully restructures toward renewables, investors slowly regain confidence and the market recovers over the medium to long term.

**Regulation.** The level of global cooperation for mitigation is high, well-coordinated, and within the next five years (2016 to 2020).

For example, the effort of climate policies aimed at reducing GHG emissions is reflected by the carbon tax imposed internationally on fossil-fuel dominant energy supply; a global carbon budget is allocated at 20% of the total underground carbon reserves (Carbon Tracker Initiative, 2013).<sup>4</sup>

Most major countries adopt the following carbon mitigation targets:

- \$100<sup>5</sup>/toe of carbon tax to reflect the strength of climate policies aimed at reducing GHG emissions
- Carbon budgets set at 20% on existing reserves
- 80% more investments<sup>6</sup> in low-carbon technologies
- No further investment (or subsidies) for fossil fuel exploration, extraction and delivery

**Direct Impacts.** Carbon taxes are implemented as an additional tax (i.e. not revenue neutral), thus they will be passed on to businesses and consumers, thereby reducing purchasing power, productivity, investment, and the economy's total output (Congressional Budget Office, 2013). However, these carbon taxes may be used to offset budget deficits or invest in research and development boosting long-term productivity and have an overall positive effect on the economy in the long run. For example, the Congress of the United States estimates a carbon tax of \$20/ton CO<sub>2</sub> would raise \$1.2 trillion in revenue during its first decade.<sup>7</sup>

Rapid improvements in energy efficiency, a decrease in the cost of renewables and the development of new agricultural technology leads to a significant reduction in carbon intensities and higher yields from agriculture.

<sup>4</sup> Unburnable Carbon 2013: Wasted capital and stranded assets (Online) <http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/02/PB-unburnable-carbon-2013-wasted-capital-stranded-assets.pdf> [Accessed: 14 Jan 2015]

<sup>5</sup> Centre for Energy and Climate Economics (Online) Available: [http://www.rff.org/centers/energy\\_and\\_climate\\_economics/Pages/Carbon\\_Tax\\_FAQs.aspx](http://www.rff.org/centers/energy_and_climate_economics/Pages/Carbon_Tax_FAQs.aspx) [Accessed: 10 Feb 2015]

<sup>6</sup> Financing a low-carbon future (Online) Available: [http://static.newclimateeconomy.report/wp-content/uploads/2014/08/NCE\\_Chapter6\\_Finance.pdf](http://static.newclimateeconomy.report/wp-content/uploads/2014/08/NCE_Chapter6_Finance.pdf) [Accessed: 11 Feb 2015]

<sup>7</sup> Congressional Budget Office, 2013. Effects of a Carbon Tax on the Economy and the Environment. [https://www.cbo.gov/sites/default/files/44223\\_Carbon\\_o.pdf](https://www.cbo.gov/sites/default/files/44223_Carbon_o.pdf)

The short-term economic outlook remains in a state of turmoil while the economy goes through a phase of readjustment and capital is reinvested in a new energy system. This leads to a period of low short-term growth caused by high volatility, stranded assets, and uncertainty in many long-term investments.

This rocky period does not persist for long and the longer-term outlook for the economy remains positive.

- Negative 3% sentiment shocks across each of the major economies for one year
- Loss in market capitalisation of fossil fuel companies by up to 50%
- Negative sentiments taper back to zero and begin to rise as markets regain confidence over the five-year period.

### Baseline

Baseline is a world where past trends continue (i.e. the business-as-usual BAU scenario), and there is no significant change in the willingness of governments to step up actions on climate change. However, the worst fears of climate change are also not expected to materialise and temperatures in 2100 are expected to range between 2°C and 2.5°C. It is most similar to RCP6.0 and SSP2.

There is some progress towards reducing resource and energy intensity (compared to historic rates), as the economy slowly decreases its dependence on fossil fuel. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others being left behind. In general, global population continues to rise, especially in low-income countries.

However, due to the lack of unified expectations regarding the future regulation relating to GHG emissions or real economic activities, there is little hope that any significant changes will happen to the existing economic conditions or climate policies over the short-term (e.g. 2016 – 2020).

**Regulations.** Global climate policy actions are delayed beyond the modelling period, with only intermediate success in reducing vulnerability to climate challenges.

- No carbon or oil tax
- World fossil fuel energy supply/production remains unchanged
- Fossil fuel dominant energy investments remain unchanged
- No technological advances to renewable energy sources

**Direct Impacts.** None in the near future but become increasingly significant beyond 2060 due to climate change. We assume the market does not respond to the future effects of climate change in this scenario.

### No Mitigation

In the No Mitigation scenario the world is oriented towards economic growth at all costs with little consideration given to the environment. Hope is placed on the role of the markets to innovate with emphasis placed on self-interest to provide adaptive responses to climate change impacts as they arise. It is most similar to RCP8.5 and SSP5. In the absence of climate policy, the preference for rapid conventional development leads to higher energy demand dominated by fossil fuels, resulting in high GHG emissions. Investments in alternative renewable energy technologies are low but economic development continues mainly driven by consumption.

The initial market volatility is high due to significant uncertainty around the future impacts of climate change. But as the world progresses under conventional development, there is growing realisation that the majority of wealth generated from strong economic performance was squandered on short-term consumption.

Thus, market confidence on future performance of the economy is adjusted downward, initiating a widespread downgrade in stock price valuations reflecting a future of low growth and low economic output.

**Regulation.** The level of global mitigation to man-made drivers of climate change is low and delayed, with no coordinated action in attributing pricing strategies to GHG emissions and land use change. In the absence of climate policies within the five-year modelling period (i.e. 2016 – 2020):

- No carbon or oil tax
- 50% increase in world fixed investment for energy extraction

**Direct Impacts.** Fossil-fuels remain the dominant source of energy, incentivising rapid technological progress in large-scale energy and natural resource exploration and extraction, significantly driving up the price of fossil fuel energy.

As the markets recognise the high growth potential in fossil fuel based assets, investment in fossil fuel company's increase, which is then spent on further exploration and extraction by these companies (ultimately leading to the high climate change scenario).

Climate change induced environmental degradation and water stress reduces agricultural yields across many parts of the world.

The increased water stress, resource constraints, and other environmental factors further strain production capabilities as well as regional social cohesion.

- 10% per year increase in global demand for carbon energy sources
- 10 – 20% per year increase in world agriculture prices due to higher cost and lower land-use availability
- Sharp sentiment shocks of up to Neg. 5 – 8% across the major economies

### Potential Scenario Triggers

There are many potential triggers that may initiate a financial tipping point brought about by market sentiment on the future effects of climate change. The triggers described below may cause the unravelling of the economic and financial system in a similar fashion to the scenarios described above.

These triggers illustrate the different types of signals that may be leading indicators in the instantaneous sentiment shocks for each scenario. Table 5 highlights five categories from which a trigger may appear and cause a financial tipping point. These categories are: new scientific evidence and technology; new policy announcements; new legal developments; increased social awareness; and other economic factors.

Trigger	Two Degrees	No Mitigation
<b>New scientific evidence and Technology</b>	<ul style="list-style-type: none"> <li>• New technological breakthrough in low carbon technology (e.g. fusion, solar)</li> <li>• Increased accuracy in the monitoring and measurement of emissions for attribution.</li> </ul>	<ul style="list-style-type: none"> <li>• New scientific evidence on the unstoppable and runaway effects of climate change</li> <li>• Thermohaline circulation shuts down</li> <li>• Permafrost melts releasing vast quantities of methane into the atmosphere</li> <li>• Greenland and Antarctica ice sheet begins to melt</li> <li>• Glaciers begins to disappear</li> <li>• Tipping points are reached</li> </ul>
<b>New policy announcements</b>	<ul style="list-style-type: none"> <li>• Announcement of global agreement to limit GHG with a tax or a cap.</li> <li>• Election of new political party that pushes climate change mitigation.</li> <li>• Forced nationalisation of selected national infrastructure and assets in the name of preventing catastrophic climate change</li> <li>• Commitment to stop the implicit subsidy of fossil fuels.</li> </ul>	<ul style="list-style-type: none"> <li>• Chaos and breakdown in global discussion on GHG policy</li> <li>• Continued subsidy and government action to open new oil fields.</li> <li>• Rollback on the price of carbon from all major economies (e.g., China, Europe, USA)</li> </ul>
<b>New legal developments</b>	<ul style="list-style-type: none"> <li>• Introduction of new case law on the legality of emitting CO2 emissions based on existing law.</li> <li>• Increase in the number of lawsuits and liabilities placed against companies that emit CO2 or companies with a disregard for the environment.</li> </ul>	<ul style="list-style-type: none"> <li>• Climate change mitigation legal challenges defeated in court</li> </ul>
<b>Increased social awareness</b>	<ul style="list-style-type: none"> <li>• Increasing social awareness on the risk of GHG emissions and increasing reputational risk for companies that emit GHG.</li> <li>• Increased social awareness and pressure from share-holders, employees and activists to reduce emissions.</li> </ul>	<ul style="list-style-type: none"> <li>• Increasing social awareness of changing growing seasons and lower agricultural yields</li> <li>• Increase mechanization and carbon-intensity on farmlands for fear of failed crops</li> </ul>
<b>Economic factors</b>	<ul style="list-style-type: none"> <li>• Achievement of price parity between renewable technology and fossil fuels</li> <li>• Stranded fossil fuel assets</li> </ul>	<ul style="list-style-type: none"> <li>• Persistent low fossil fuel prices</li> <li>• Clean technology bubble collapse</li> </ul>

**Table 5: Potential triggers that may lead to the development of each sentiment scenario**



## 6 Macroeconomic analysis

### Implementing the macroeconomic analysis

The effects of human activity over the next two decades will either put the Earth on a path to limiting an increase in temperature below 2°C compared to pre-industrial era temperatures, or commit the planet to temperature increases above 4°C or more.

While the most likely scenario will be somewhere between these two extreme scenarios, it is nonetheless important to conduct ‘what if’ analysis to understand the implications for what these scenarios might indicate for the economy. Cost-benefit analysis is the most common approach used within the literature for estimating the discounted future costs of climate change, and attempts to estimate all potential future costs and benefits across different climate change scenarios before discounting these estimates into present day dollars.

These estimates are often used to calculate the marginal cost of emitting a tonne of CO<sub>2</sub>. In this analysis we do not conduct a cost-benefit analysis, nor use an Integrated Assessment Model (IAM) to estimate the costs and benefits of different climate change scenarios. Instead, this report draws on several other studies (Ackerman and Stanton, 2006; The Economist, 2015; 2008) to inform the development of the sentiment scenarios and for conducting the macroeconomic analysis.

As part of the long-term economic impacts of each sentiment scenario, a net present value calculation (NPV) is completed to compare the continuing impact on global GDP with respect to the baseline scenario. With a discount rate of 6% over the period 2015 – 2050 the Two Degrees scenario has an economic benefit over Baseline of 3.2%, while the No Mitigation scenario has a long-term cost to the economy of approximately 14%. As economic growth is cumulative this means economic output in the No Mitigation scenario is 25% below baseline output.

We use sentiment indicators as surrogates for awareness or perception of the economic impacts of climate risk by the public, policy-makers and investors alike, in order to drive the macroeconomic analysis. The ambiguous concept of economic sentiment is usually neglected by macroeconomists because it is not a variable easily observable or quantifiable (van Aarle and Kappler, 2012), and often dismissed as a psychological or subjective component of beliefs (Arias, 2014).

Nevertheless, the effect of sentiment shifts on the macroeconomy can be significant.

In this analysis we attempt to capture market sentiment using plausible stress test scenarios. A significant part of the sluggish recovery following a downturn can also be attributed to the pessimistic view held by markets.

Negative or risk averse actors play a significant role during recessions – during the hyperinflation period of the 1970’s and beginning of the 80’s. The wave of weak confidence reinforced the downturn by further driving growth rates downwards, even though economic fundamentals may have already recovered (Arias, 2014).

### The Oxford Economics’ General Equilibrium Model (GEM)

We use the Oxford Economics’ GEM<sup>1</sup>, a quarterly-linked global econometric model, to examine how the global economy reacts to shocks of various types. It is the most widely used international macroeconomic model with clients including the IMF and World Bank. The model contains a detailed database with historical values of many economic variables and equations that describe the systemic interactions among the most important 47 economies of the world. Forecasts are updated monthly for the 5-year, 10-year and 25-year projections.

The Oxford Economics’ GEM is best described as an eclectic model, adopting Keynesian principles in the short-term and a monetarist viewpoint in the long-term. In the short-term, output is determined by the demand side of the economy; while in the long-term, output and employment are determined by supply side factors. The Cobb-Douglas production function links the economy’s capacity (potential output) to the labour supply, capital stock, and total factor productivity. Monetary policy is endogenised through the Taylor rule, when central banks amend nominal interest rates in response to changes in inflation or economic growth. Relative productivity and net foreign assets determine exchange rates and trade is the weighted-average of the growth in total imports of goods (excluding oil) of all remaining countries. Country competitiveness is determined from unit labour cost.

<sup>1</sup> The Oxford Economics’ Global Economic Model (GEM) is a rigorous quantitative modelling tool for forecasting and scenario analyses. [Online] Available on: <http://www.oxfordeconomics.com>

**Table 6: Key input variables and their maximum shocks applied to the respective scenario variants**

S/N	Macroeconomics Input Variable	Sentiment Scenarios			Shock duration applied
		Two Degrees	Baseline	No Mitigation	
<b>1</b>	<b>Carbon Tax</b>				
	Global	+US\$100/toe <sup>^</sup>	Nil	Nil	5 years
<b>2</b>	<b>World Fixed Investment for Energy Extraction</b>				
	Global	-80%	Unchanged	+50%	5 years
<b>3</b>	<b>Green investments</b>				
	Global	+80%	Unchanged	Nil	5 years
<b>4</b>	<b>World Energy and Food Prices</b>				
	Global	Unchanged	Unchanged	+100%	5 years
<b>5</b>	<b>Global Energy Demand</b>				
	Global	-10%	Unchanged	Unchanged	5 years
<b>6</b>	<b>Market Confidence</b>				
	 United States	-3	Unchanged	-5	4 quarters
	 United Kingdom	-3		-5	
	 Germany	-3		-5	
	 Japan	-3		-5	
	 China	-3		-5	
	 Brazil	-3		-5	
<b>7</b>	<b>Bond Market Stress</b>				
	 United States	2%	Unchanged	4%	5 years
	 United Kingdom	2%		4%	
	 Germany	3%		7%	
	 Japan	3%		7%	
	 China	5%		10%	
	 Brazil	5%		10%	
<b>7</b>	<b>Housing Price Index</b>				
	 United States	3%	Unchanged	20%	4 quarters
	 United Kingdom	3%		20%	
	 Germany	5%		35%	
	 Japan	5%		35%	
	 China	5%		50%	
	 Brazil	5%		50%	

<sup>^</sup>toe = tonnes of oil equivalent

### Variable descriptions

Using the Oxford Economics' GEM, three independent scenarios simulating market sentiment shifts are modelled: Two Degrees, No Mitigation, and the Baseline. The Baseline sentiment scenario is the projection trajectory updated regularly by Oxford Economics'; it acts as the control in this study and represents the reference economic projection for comparison between the Two Degrees and No Mitigation.

Some countries are illustrated with having larger macroeconomic shocks applied as compared to others because they are subjected to higher impacts due to varying exposure levels for a given mean global temperature change.

Moreover, developed countries have greater capital stocks and infrastructure to better withstand temperature rises, thereby increase their resiliencies and correspondingly reduce the market shocks applied.

While most macroeconomic variables are shocked across the five-year modelling period to simulate the shift in consumer behaviour, consumption, and policies effects, higher volatility parameters such as confidence levels and house price indices are shocked for one year. Thus, the model simulates both longer-term behavioural changes, and policy impacts, and the instantaneous market shocks.

Table 6 shows the shocks that were applied to eight different macroeconomic variables that cut across countries and regions within the Oxford Economics' GEM. Shocks were carefully considered based on their magnitude, spatial impact and duration across each scenario variant.

The remainder of this section further describes each of the variables and the underlying rationale for the respective shocks that were applied:

**Carbon Tax.** Within the literature there is a huge range of estimates for the social cost of carbon (SCC) which range from \$50/tCO<sub>2</sub> to well above \$300/tCO<sub>2</sub> (Stern, 2007; Tol, 2008). However, in order to stay within the 2°C limit by 2100, we anticipate that the price of CO<sub>2</sub> will have to be in the range \$250-\$300/tCO<sub>2</sub>.

In another study completed by Moore (2014), the upper-bound mitigation cost for avoiding dangerous climate change was estimated to be around \$300/tCO<sub>2</sub>, which is equivalent to the model estimate of \$100/toe. This carbon price thus reflects the global response and policies of the Two Degrees Scenario. In the No Mitigation scenario no carbon tax has been applied.

### World Investment for Fossil Fuel Extraction.

In the Two Degrees scenario, together with high carbon taxes and the removal of fossil fuel subsidies, investment in new renewables and low confidence in the performance of fossil fuels over the long-term is expected to drive down new investment in fossil fuel extraction by up to 80% in the short-term.

In the No Mitigation scenario, the high energy prices drive a positive long-term outlook in the performance of the fossil fuel based industries; which in turn renews interest in exploration and extraction investment in fossil fuel based sectors by up to 50% over the short-term, thereby increasing worldwide carbon-intensive energy sources.

**Non-Fossil Fuel based Investment.** In the Two Degrees scenario, the increase in spending for non-fossil fuel based investments is financed through carbon tax revenues, commonly referred to as revenue recycling within the literature studied. The increase in non-fossil fuel investment also represents a shift in investment away from fossil fuels into non-fossil fuel based investments. In the No Mitigation scenario, non-fossil fuel based investments are modelled endogenously.

**World Energy and Food Prices.** In the Two Degrees scenario, increased energy efficiency and lower concerns about the future effects of climate change mean that food and energy prices remain stable.

In contrast, in the No Mitigation scenario, the long-term outlook for agricultural yields brought about by future climate change encourages hoarding and speculation about the future availability of food, driving up prices over the short-term.

Furthermore, in the No Mitigation scenario there is increasing speculation about the possibility of future fossil fuel resource constraints (i.e. peak oil and gas) coupled with strong short-term demand and expectations that demand for fossil fuels will outstrip production capacity, and that limits on supply will drive up energy prices over the near term.

**Global Fossil Fuel Demand.** In the Two Degrees scenario, increases to energy efficiency, a shift towards renewables and additional taxes on carbon are expected to reduce global fossil fuel demand by 10%. This assumes that the long-term transition to renewables takes much longer than the five-year modelling period and that fossil fuels remain an important energy source - at least in the medium-term. On the other hand, under the No Mitigation scenario, global energy demand for fossil fuels remains at historical rates over the five-year modelling period.

However, over the long-term as the economy becomes increasingly reliant on fossil fuels as a source of energy, global energy demand is expected to outstrip supply even though investments in fossil fuel extraction are expected to increase. This is because the extraction of fossil fuels from increasingly remote locations drives up costs over the long-term, increasing prices over the short-term due to speculation.

**Confidence Shock.** Confidence shocks are collectively applied across both developed and emerging economies, and in both Two Degrees and No Mitigation scenarios. The confidence shocks being applied reflect each country's level of vulnerability and resilience to manage climate change. The magnitude of confidence shocks applied reflects the level of expected financial market performance under each scenario. As a relativity check, the magnitude of the most severe confidence shock applied is approximately half the size of the confidence shock from the 2008 Great Financial Crisis.

**Long-Term Interest Rates.** Long-term interest rates indicate stresses in the bond market, which reflect the weak expectation for future growth in countries most vulnerable to climate change. The shocks applied differ across developed and developing countries, primarily due to the different maturity of the bond markets and vulnerability to climate change impacts.

In the Two Degrees scenario, interest rates increase because governments need to borrow to pay for new energy infrastructure, adding additional pressure to the already strained government balance sheets. This has the effect of downgrading country credit ratings, putting positive pressure on interest rates over the short-term. In the No Mitigation scenario interest rates also increase, reflecting the chaos and uncertainty that markets have in bond markets and the inability of governments to make any firm commitments to deal with the effects of climate change - particularly for the countries most impacted. In this scenario, governments also recognise the need to raise revenue to pay for future climate change adaptation strategies, similarly placing additional strain on already stressed government balance sheets.

**Housing Price Index.** In the No Mitigation scenario, the physical impacts from climate change, including sea level rise, storm surges, extreme weather events, among others, will inevitably destroy homes and reduce the amount of viable land for building homes. Decreased availability of housing and the additional costs of recovery and reconstruction are expected to increase the cost of housing. Low supply and high demand will inevitably drive up prices, putting positive pressures on the house price index.

The expected strong growth in the underlying house price index creates speculation in the short-term for good quality homes not at risk from climate change, driving up prices.

Furthermore, the rural-to-urban migration in search for higher amenities from cities better prepared for climate impacts also drives up prices, particularly in urban environments. On the demand side, increasing numbers of climate refugees will increase demand for new homes in less vulnerable places, exacerbating price increases even further. In the Two Degrees scenario, new household energy efficiency regulation will require many homes to be renovated to very high energy standards, with many older and inefficient homes needed to be demolished.

This is expected to drive up the cost of homes as speculation regarding the cost of new policy reaches the market. This effect is not thought to be as large as in the No Mitigation scenario and benchmarked to historical variability.

### Macroeconomic results

The following section presents the macroeconomic outputs in the short-term, 2016 – 2020, based on the GDP@Risk metric calculations for each of the three sentiment scenarios. A simple long-term macroeconomic analysis, from 2016-2050, is presented in Section 6, followed by a comparison between the short and long-term outcomes on page 32.

Macroeconomic and financial market outputs for this analysis are derived using the Oxford Economics' GEM driven by a set of exogenous macroeconomic input shocks. These input shocks represent changes in commodity prices, shifts in climate policy and shifts in market sentiment from the scenario narratives. The sensitivity of our results and the Oxford Economics' model validation to the market confidence parameter are further explored in Box 1 and Box 2 at the end of this section.

Table 6 summarises the key macroeconomic impacts due to climate risks modelled across the sentiment scenarios: (i) growth rates and (ii) GDP figures. By definition, the technical indicator of a recession is two consecutive quarters of negative economic growth. Table 6 illustrates a global recession occurs for up to three quarters in the No Mitigation scenario, where the global economy shrinks by up to 0.1% (Q-on-Q) compared to the baseline quarterly growth projection of 0.7%. Another main macroeconomic output modelled is a year-on-year projection of the global economy. The impacts of each sentiment scenario are compared to the baseline projection in which no crisis occurs.



The loss in expected economic output over the five-year period between the baseline and each sentiment scenario represents the GDP@Risk metric.

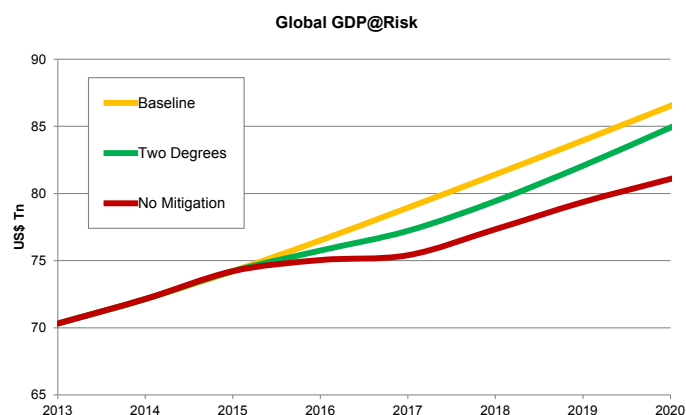
The total GDP (expected output) loss over five years, beginning in the first quarter of 2016 during which the shock of climate risk is applied and then sustained through to the last quarter of 2020, defines the GDP@Risk. This is further expressed as a percentage of the total GDP projection for the five years without the crisis occurring.

Table 7 also provides the GDP losses of each scenario globally and across selected countries, both as the expected total lost economic output over five years, and in percentage terms over the original projected economic output from 2016 to 2020.

Figure 8 illustrates the dip in global GDP that is modelled to occur as a result of climate risk, across all sentiment scenarios.

### Long term impacts

The long-term economic impacts for each sentiment scenario are also analysed based on the underlying assumption that the sentiment shift in each case is consistent with the subsequent physical changes in the respective climatic conditions. The starting point for estimating the long term impacts includes running the GEM for a further five years out to 2025.



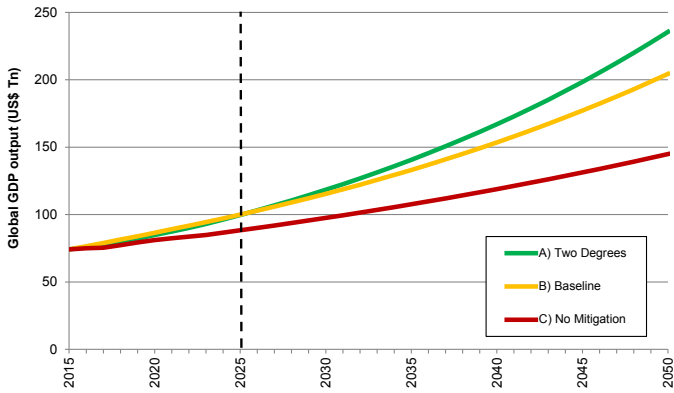
**Figure 8: Estimated modelled economic loss in global output (GDP@Risk)**

This allows the Oxford Economic's, a general equilibrium model, to re-equilibrate to a new long-term growth trajectory based on the new economic conditions brought about by the first five years of modelling.

From 2025 to 2050, we assume the annual growth rate of the global economy remains stable at the annual growth rate estimated in year 10 (2025). This compounding economic growth rate is then used to estimate annual global GDP levels to 2050. This approach is justified because the further out into the future economic output is projected, the greater is the uncertainty of those estimates.

**Table 7: Summary of macroeconomic impacts across the sentiment scenarios modelled**

Macroeconomics Impact	Sentiment Scenarios				
	Baseline	Two Degrees		No Mitigation	
<b>Global variables</b>					
<b>Min. qtrly growth rate</b> (Global Recession Severity)	0.7%	0.3%		-0.1%	
<b>Global Recession Duration</b>	N/A	N/A		3 Qrts.	
<b>Economic output</b>	<b>5-yr GDP (US\$ Tn)</b>	<b>GDP@Risk (US\$ Tn)</b>	<b>GDP@Risk (%)</b>	<b>GDP@Risk (US\$ Tn)</b>	<b>GDP@Risk (%)</b>
<b>Global</b>	<b>407.3</b>	<b>8.9</b>	<b>2.2%</b>	<b>19.1</b>	<b>4.7%</b>
<b>United States</b>	91.4	3.0	3.2%	7.6	8.4%
<b>United Kingdom</b>	14.3	0.3	1.7%	0.8	5.8%
<b>Germany</b>	19.3	0.3	1.5%	0.7	3.8%
<b>Japan</b>	29.5	0.1	0.4%	0.6	2.3%
<b>China</b>	51.1	2.4	4.7%	4.6	9.0%
<b>Brazil</b>	12.3	0.4	3.5%	0.8	6.3%



**Figure 9: Comparison of the long-term GDP projections across the sentiment scenario variants**

Therefore maintaining economic growth at the best long-term estimate is a good first-order approximation, absent any additional information. The long-term annual growth rates estimated from year 10 are 3.5%, 2.9% and 2.0% for the Two Degrees, Baseline and No Mitigation sentiment scenarios, respectively. Evidently, the higher the annual growth rates drive higher long-term cumulative outcomes, which we give details of next.

The results of this analysis are shown in Figure 9. Over this longer time horizon from 2015 to 2050, the divergence between the different sentiment scenarios becomes much more pronounced.

The initial sentiment shock to the global economy cumulated over the first five years is negligible, relative to the longer term cumulative impacts of climate change. We show that over the longer term, a rise in average global temperatures of not more than 2°C is beneficial to the global economy due to a higher annual economic growth rate than the Baseline and No Mitigation scenarios.

The long-term cumulative costs and benefits for each scenario over the 35-year period between 2015 and 2050 are displayed in Table 7.

When compared to the Baseline scenario using a discount rate of 3.5%, the Two Degrees scenario is shown to have a cumulative 4.5% beneficial global impact output, while the No Mitigation scenario is shown to have a cumulative negative impact of 16%. Another way of looking at this is to say that the economic output in the No Mitigation scenario is 25% below baseline in 2050 while the Two Degrees Scenario is 15% greater than baseline.

The difference in economic output between the No Mitigation Scenario and Two degrees Scenario could be as high as 40% by 2050 based on these estimates.

**Economic conclusions**

Although the physical effects of climate change will have limited impacts on the economy over the next five to 10 years, the effects of climate policy and market sentiment may cause significant economic disruption. The short-term economic impacts of both No Mitigation and Two Degrees have negative consequences for the global economy.

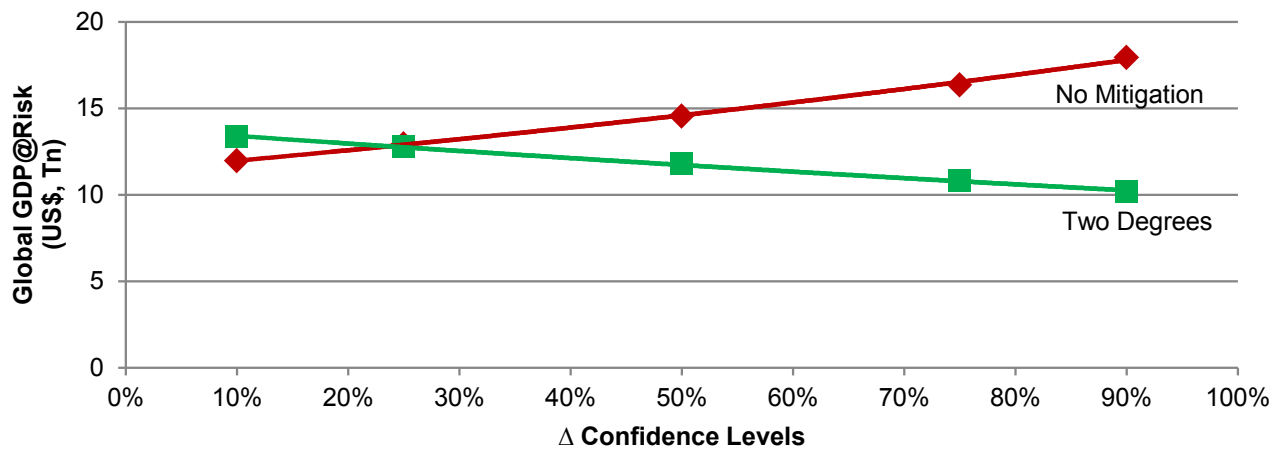
The No Mitigation scenario causes a global recession for the first three quarters of the analysis period. The Two Degrees scenario does not cause a global recession but slows the economic growth to half when compared to Baseline. In the No Mitigation scenario the economy suffers an economic loss that continues indefinitely, representing an all-time and ongoing loss to global economic output. In the Two Degrees scenario the economy performs worse than Baseline for the first 8 to twelve years, but then recovers and grows much faster than the Baseline scenario.

Using a discount rate of 3.5% over 35 years, the Two Degrees scenario outperforms the Baseline scenario by 4.5% while the No Mitigation scenario under performs against Baseline by 16%.

Cumulative Long Term Impacts of Scenarios with Respect to Baseline			
Scenario	No Discount Rate	3.5% Discount Rate	6% Discount Rate
Two Degrees	6.5%	4.5%	3.2%
No Mitigation	-19%	-16%	-14%

**Table 8: Long-term impacts with respect to Baseline**

**Box 1: Sensitivity analysis of the macroeconomics**



**Figure 1A: Sensitivity of GDP@Risk values with varying confidence levels**

Sensitivity analysis challenges the key quantitative assumptions by systematically changing the simulation computations to assess their effects on the final outcomes. For example, in this study, market confidence is one of the main economic drivers of the economic impact assessment; therefore the magnitude of the confidence level shock across countries being studied needs to be analysed. Here we perform a sensitivity analysis to show the effects of a confidence shock on the overall results.

At a 10% difference in confidence levels while keeping all other input parameters constant; the modelled economic impact (5-year global GDP@Risk value) from the Two Degrees scenario is marginally larger than the No Mitigation (Figure A1). This is consistent with the climate policy assumptions made in the scenario narratives should we not take into consideration the psychological effects of the market.

In the Two Degrees scenario, transition to a low-carbon economy causes capital to be lost from stranded fossil fuel assets incurring immediate costs, this combined with the implementation of carbon taxes and uncertain transition period reduces total output productivity. Whereas, focusing only on rapid economic development in No Mitigation increases profitability of fossil fuel investments having direct and immediate positive impacts on economic growth. Thus, from an economic perspective with minimal sentiments effects, the potential output at risk is relatively higher in a rapid low-carbon transition scenario.

On the contrary, significant negative sentiments shifts and shrinking consumption patterns in the No Mitigation scenario represent far greater potential output at risk by up to 40%, in comparison to Two Degrees.

While this study does not quantify the correlation between economic sentiment and impact, it has validated that sentiment indicators are one of the main drivers of economic market performances. Therefore, market confidence is a necessary parameter in the study to capture the effects of human behaviour in modelling climate risk and assessing its economic and financial impacts. However, market confidence is just one of the drivers and by no means dominates the analysis.

### **Box 2: Oxford Economics' model validation and the confidence shocks to markets**

The Oxford Economics' GEM is often used as a tool for scenario analysis and stress testing. The GEM allows conducting rigorous "what-if" analyses, and to look at the implications of key economic risks and policy changes when there are extreme shifts in economic conditions.

The Oxford Economics' GEM is a widely used macroeconomic model by financial corporations, consultancies, and government departments. Multilateral organisations like the International Monetary Fund, the United Nations, and the World Bank have also used this model to conduct economic analysis. .

One example scenario produced by Oxford Economics is the Global Economic Scare Scenario, where financial markets across the world grow increasingly concerned over foreign growth expectations. Besides a marked slowdown in global activities, sentiments are shocked by 100% across businesses, consumers, and investors to indicate a complete breakdown of confidence in the market and a decline in long-term economic outlook. The confidence shocks applied in the development of the climate change sentiment scenarios presented in this report always remain below 10%, ensuring the scenario is both plausible and possible, even with a low likelihood of occurrence.

Another more recent stock market crash occurred in China, which began with the popping of the stock market bubble on 12 June 2015. The crash in the SSE index was estimated to have a peak-to-trough decline of over 40%. Using the inverse of the volatility S&P index ( $\hat{VIX}$ ), a suitable proxy for market confidence, we show a peak-to-trough decline of 57% over the same period.

We also show a close correlation between market performance and market confidence ( $R=0.64$ ). While sentiment plays an important role in market performance, the magnitude of the confidence shock applied in these scenarios are much lower than historical precedents, thus reflecting the plausibility of the scenarios defined in this analysis.



## 7 Investment portfolio analysis

The macroeconomic effects of the climate impact sentiment scenarios will have an inevitable effect on the financial capital markets. This section considers the market impact of the scenarios and corresponding consequences for investors in the capital markets.

The performance of bonds, equities and alternatives in different markets is estimated from the macroeconomic modelling, and compared with a baseline projection of their respective expected performance that would result without the scenario occurring.

### Valuation fundamentals

Note that our goal here is to estimate how the fundamentals of asset values are likely to change as a result of various market conditions, at least in directional terms.

This analysis is not a prediction of daily market behaviour and does not take into account the wide variations and volatility that can occur in asset values due to trading fluctuations and the mechanisms of the market.

### Passive investor assumption

A fundamental assumption in the analysis is that of considering a passive and “traditional” financial portfolio investment strategy in which the proportions of different types of assets are fixed in advance, and are held constant via real-time rebalancing throughout a given period.

Although this assumption is unrealistic, as an asset manager is expected to react to changing market conditions in order to rebalance risk across sectors and geographies within an asset class, and asset owners across asset classes, it is a useful exercise to consider what might happen to a fixed portfolio.

This is also necessary as a benchmark representation against which active fund managers can compare the performance of dynamic strategies.

This assumption further provides the understanding of what drives the behaviour of a fixed portfolio at different times, drawing attention to investors whether improved portfolio management processes are required and gives greater insights towards designing the optimal investment strategy.

### Standardised investment portfolios

This study considers four typical high quality investment portfolios that have been designed in consultation with the advisory panel with representatives from the financial services industry and insurance. They are fictional representative portfolios that mimic features observed in the investment strategies of insurance companies (High-Fixed Income Portfolio) and pension funds (Aggressive, Balanced and Conservative). For example, the Conservative Portfolio structure has 59% of investments in sovereign and corporate bonds, of which 95% are rated A or higher (investment grade), 40% in equity markets and commodities make up the remaining 1% of the portfolio structure.

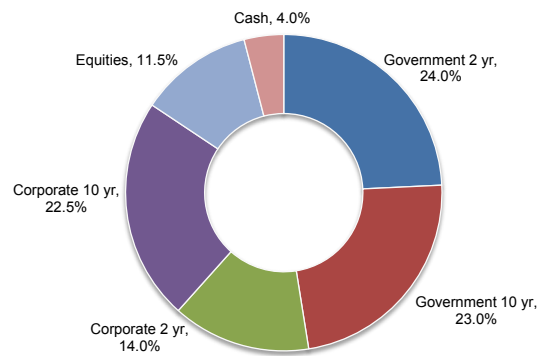
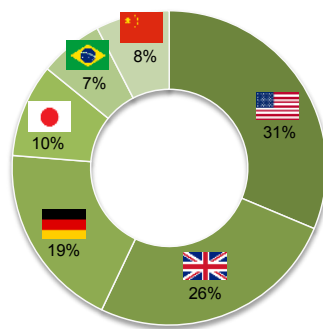
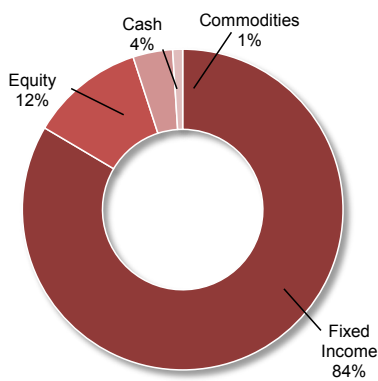
The portfolio structures cover several asset classes and are geographically diverse.

Investments spread across the developed markets of the US, UK, Germany and Japan, as well as the emerging markets of Brazil and China. The 40% equity investments correspond to investments in stock indices. The Wilshire 5000 Index (W5000), FTSE100 (FTSE), DAX (DAX) and Nikkei (N225) are used to represent equity investments in the developed markets, while the Boverspa (BVSP) and SSE Composite Index (SSE) represent the emerging markets.

The maturity for long-term fixed-income bonds is assumed to be 10 years, while that of the short-term bonds are either three-months or two years, limited by the macroeconomic model outputs for each country.

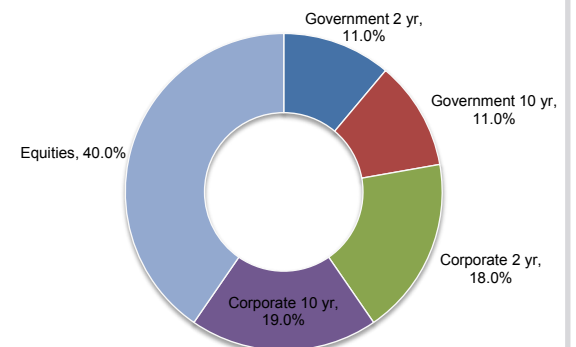
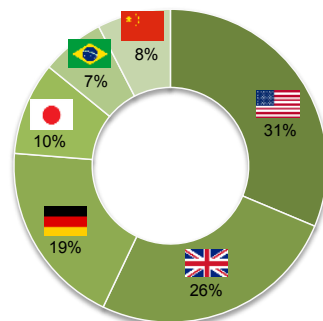
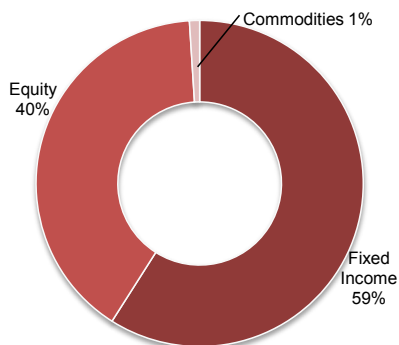
Details of the High Fixed Income Portfolio:

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	8.0%	6.0%	4.5%	2.5%	1.5%	1.5%	0.0%	24.0%
Government 10 yr	7.0%	7.0%	5.5%	1.5%	1.0%	1.0%	0.0%	23.0%
Corporate 2 yr	3.0%	3.0%	3.0%	2.0%	1.5%	1.5%	0.0%	14.0%
Corporate 10 yr	6.0%	7.0%	3.0%	2.5%	1.5%	2.5%	0.0%	22.5%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	3.0%	2.5%	3.0%	1.0%	1.0%	1.0%	0.0%	11.5%
Cash	4.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	1.0%
<b>Total</b>	<b>31.0%</b>	<b>25.5%</b>	<b>19.0%</b>	<b>9.5%</b>	<b>6.5%</b>	<b>7.5%</b>	<b>1.0%</b>	<b>100.0%</b>



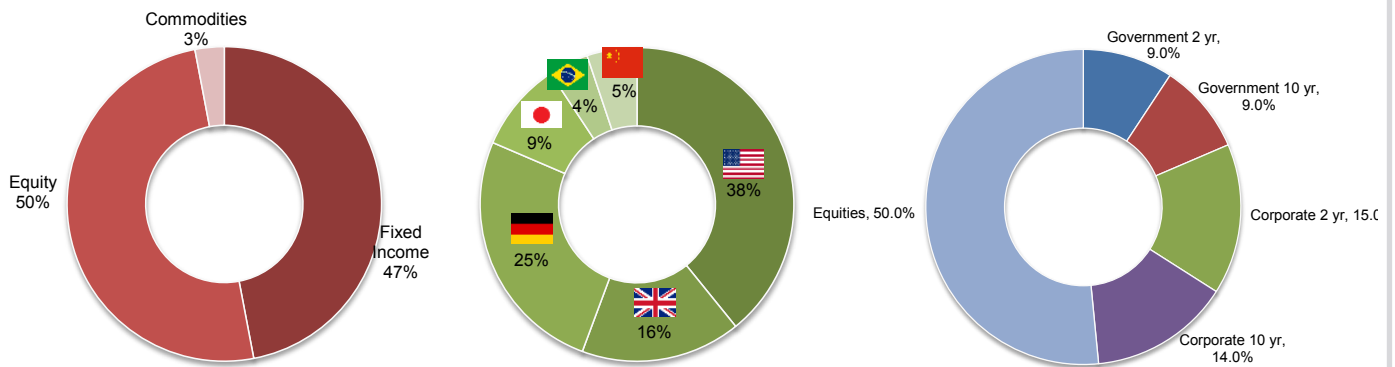
Details of the Conservative Portfolio:

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	4.0%	2.0%	3.0%	0.0%	1.0%	1.0%	0.0%	11.0%
Government 10 yr	3.0%	2.0%	3.0%	1.0%	1.0%	1.0%	0.0%	11.0%
Corporate 2 yr	5.0%	4.0%	5.0%	2.0%	1.0%	1.0%	0.0%	18.0%
Corporate 10 yr	5.0%	4.0%	5.0%	3.0%	1.0%	1.0%	0.0%	19.0%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	19.0%	8.0%	8.0%	5.0%	0.0%	0.0%	0.0%	40.0%
Cash	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	1.0%
<b>Total</b>	<b>36.0%</b>	<b>20.0%</b>	<b>24.0%</b>	<b>11.0%</b>	<b>4.0%</b>	<b>4.0%</b>	<b>1.0%</b>	<b>100.0%</b>



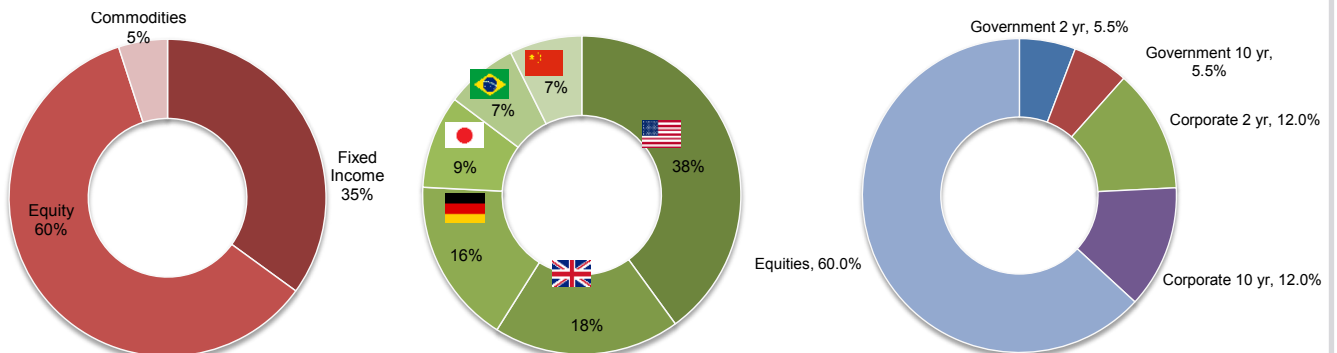
Details of the Balanced Portfolio:

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	3.0%	1.0%	3.0%	1.0%	0.5%	0.5%	0.0%	9.0%
Government 10 yr	3.0%	1.0%	3.0%	1.0%	0.5%	0.5%	0.0%	9.0%
Corporate 2 yr	4.0%	3.0%	5.0%	2.0%	0.5%	0.5%	0.0%	15.0%
Corporate 10 yr	5.0%	2.0%	5.0%	1.0%	0.5%	0.5%	0.0%	14.0%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	23.0%	9.0%	9.0%	4.0%	2.0%	3.0%	0.0%	50.0%
Cash	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.0%	3.0%
<b>Total</b>	<b>38.0%</b>	<b>16.0%</b>	<b>25.0%</b>	<b>9.0%</b>	<b>4.0%</b>	<b>5.0%</b>	<b>3.0%</b>	<b>100.0%</b>



Details of the Aggressive Portfolio:

Asset Class	USA	UK	Germany	Japan	Brazil	China	World	Total
Government 2 yr	2.0%	1.0%	1.0%	0.5%	0.5%	0.5%	0.0%	5.5%
Government 10 yr	2.0%	1.0%	1.0%	0.5%	0.5%	0.5%	0.0%	5.5%
Corporate 2 yr	4.0%	2.5%	2.0%	1.5%	1.0%	1.0%	0.0%	12.0%
Corporate 10 yr	4.0%	2.5%	2.0%	1.5%	1.0%	1.0%	0.0%	12.0%
RMBS 2 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RMBS 10 yr	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equities	26.0%	11.0%	10.0%	5.0%	4.0%	4.0%	0.0%	60.0%
Cash	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Commodities	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	5.0%
<b>Total</b>	<b>38.0%</b>	<b>18.0%</b>	<b>16.0%</b>	<b>9.0%</b>	<b>7.0%</b>	<b>7.0%</b>	<b>5.0%</b>	<b>100.0%</b>



**Computation of returns**

The estimation of portfolio returns is carried out using the following method.

Market price changes or Mark to Market (MtM) are calculated for all government bonds using equation (1) and for corporate bonds and RMBS using equation (2):

$$(1) \Delta MtM_{Gov,t} = (D_b)(-\Delta I/100)$$

$$(2) \Delta MtM_{Corp,t} = (D_b)(-\Delta I/100) + (SD_b)(-\Delta CS/100)$$

Where  $D_b$  is the bond duration, for which we assumed the following values:  $D_b = 7$  for ten years bonds and  $D_b = 1.8$  for two years bonds.  $SD_b$  represents the spread duration. The change in interest rates,  $\Delta I$  on government and corporate bonds and the change in credit spreads,  $\Delta CS$  are taken from the output of the macroeconomic analysis discussed in the previous chapter.

Government bond yields are estimated using a representative quarterly yield. While corporate and RMBS yields are estimated using a representative quarterly yield and the period averaged credit spread.

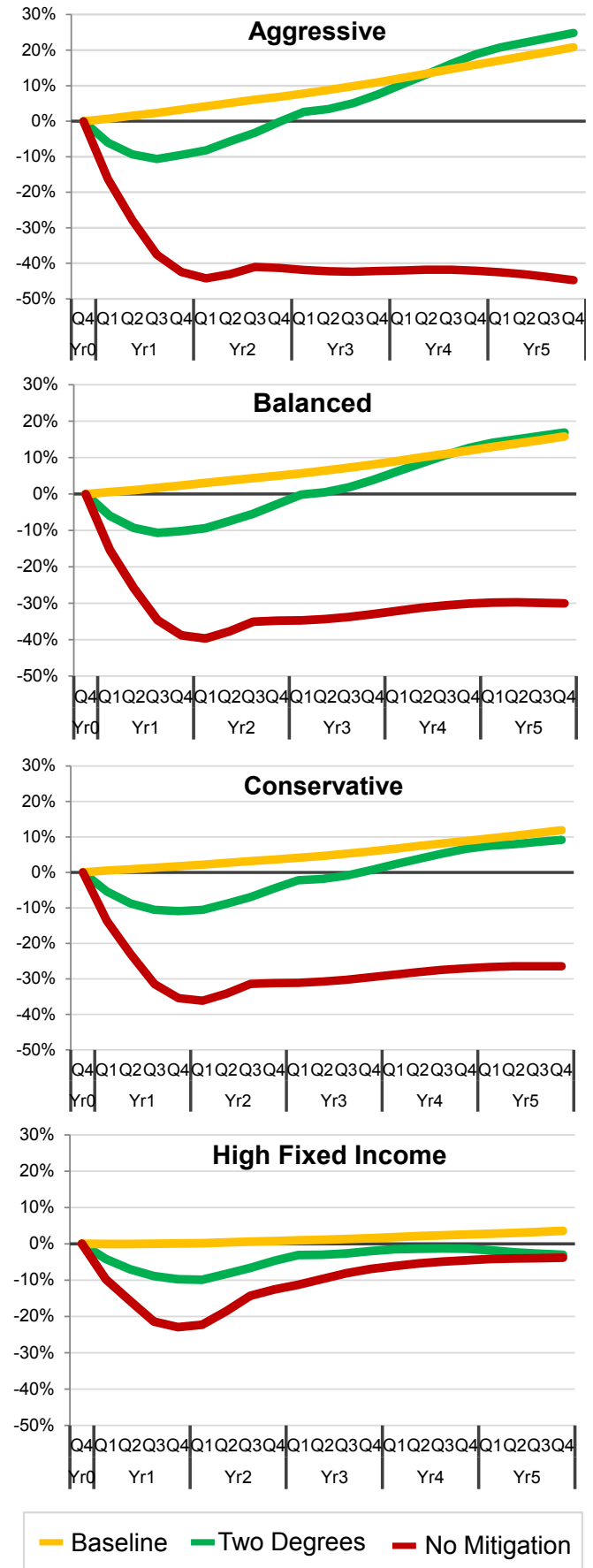
Equities market prices are calculated using the change in equity value from the macroeconomic modelling. The equity dividends are estimated using a representative quarterly yield. Exchange rate affects are taken into account to ensure all reported portfolio returns are illustrated in US dollars.

Figure 10 shows the scenario impacts by variant across all four portfolio structures by comparing in terms of total portfolio nominal returns. Across all portfolio structures and scenarios, there are significant deviations from the baseline projections during the first year of the economic shocks, applied over a five-year period starting in 2016 Q1.

In the No Mitigation scenario, the Aggressive portfolio performs the worst; recording a maximum loss of negative 45% and returns are not restored to baseline projection levels, registering a permanent loss. This is consistent with theory on the economics of climate change, which also calculates a loss into perpetuity. What is different in this result is that these losses have a real and immediate impact on the balance sheets of companies and do not represent a hypothetical future value discounted into present day values.

For the Two Degrees scenario the Aggressive portfolio suffers the largest loss and recovers relatively quickly performing better than baseline by the end of the five year modelling period.

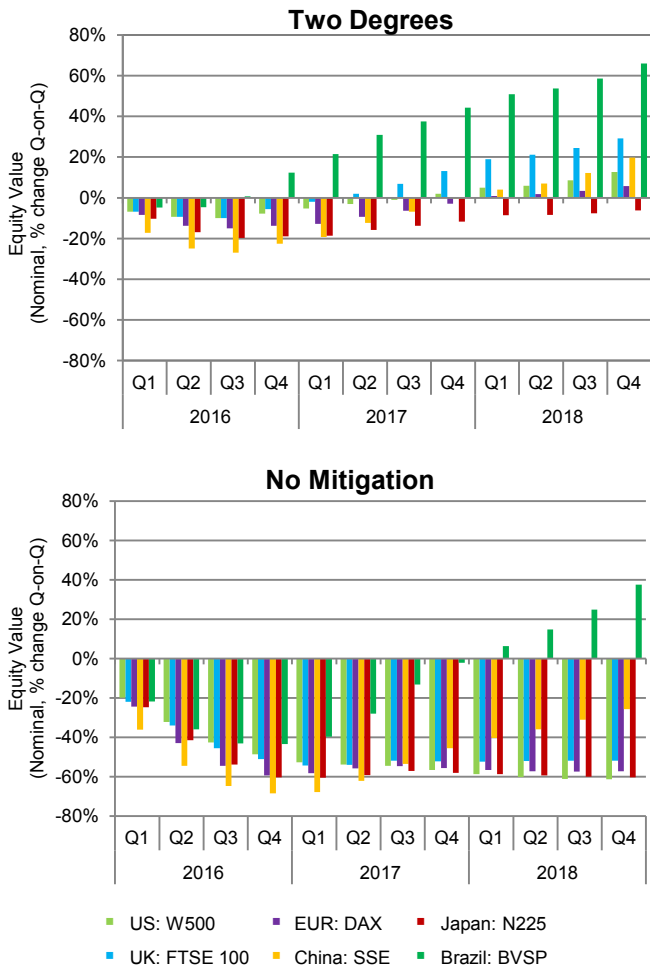
This trend is consistent with asset class performance, where economic shocks have the largest impact on equities, resulting in the Aggressive portfolio to react the most as it has the largest equity allocation weights.



**Figure 10: Comparison of total portfolio returns across sentiment scenarios**

Regardless of the sentiment scenarios studied, holders of the High Fixed Income portfolio will be least at risk of any financial market disruption. However, this portfolio also experiences low performance and small overall gains.

**Impact on Returns – by Asset Class and Geography**

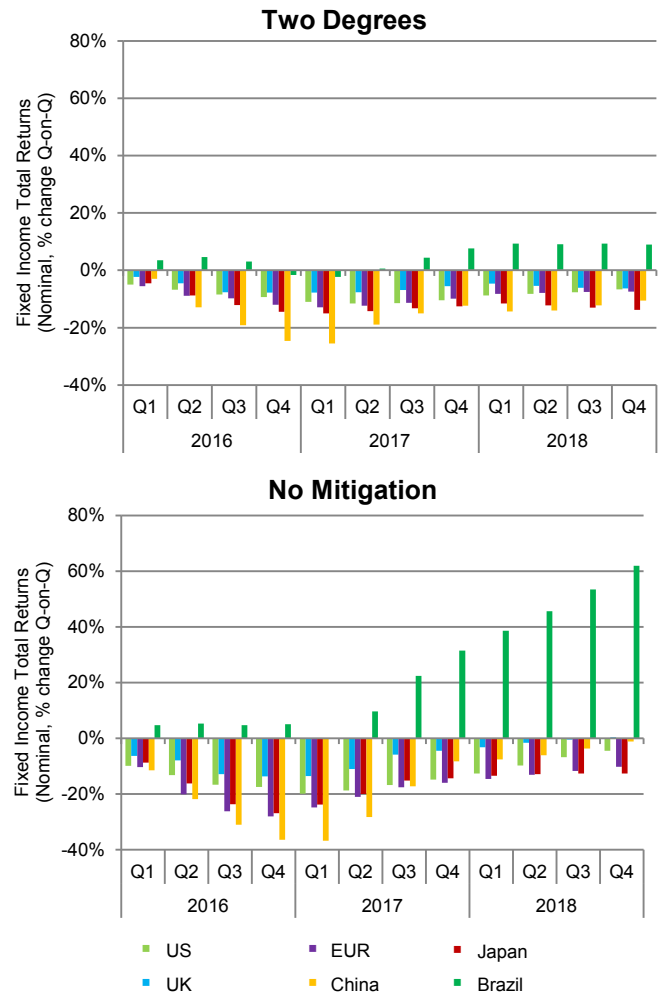


**Figure 11: Comparison of equity performance by geography in nominal % change across sentiment scenarios**

Figure 11 shows market impacts on equity performance by geography, where the country-specific impacts primarily results from the degree of vulnerability of each country’s economic fundamentals and responses to the applied shocks.

In the Two Degrees scenario, the US (W5000), UK (FTSE), Europe (DAX) and Brazil (BVSP) recover quickly from losses to generate positive returns by the second year.

However, across both scenarios, the Chinese (SSE) stock index is the most negatively impacted and does not recover after three years, indicating that the Chinese financial markets are particularly vulnerable to the effects of climate change.



**Figure 12: Comparison of fixed income performance by geography in nominal % change across sentiment scenarios**

Figure 12 shows the market impacts on fixed income performance by geography. The overall negative impact on fixed income is not as significant as equities; the largest negative fixed income loss recorded is 36%, as compared to 68% for equities which is almost twice as large. This suggests that equities are more volatile than fixed income assets in these scenario analyses, therefore the aggressive portfolio reacts the most across the sentiment scenarios.

**Impact on Returns – by Industry sector**

The impact on equity returns by industry is calculated based on the respective sectors’ betas, which represent the sectors’ volatility to the respective market indices.

Both levered and unlevered beta values by industry and across countries, compiled annually by Professor Aswath Damodaran from the Stern School of Business at New York University, are retrieved online<sup>1</sup> and analysed to better model the sectoral impacts.

<sup>1</sup> Damodaran, A. (2015) Current dataset for levered and unlevered betas by industry. [Online] Available on: [http://people.stern.nyu.edu/adamodar/New\\_Home\\_Page/datacurrent.html](http://people.stern.nyu.edu/adamodar/New_Home_Page/datacurrent.html) (Assessed 24 Feb 2015)



Beta is a measure of the volatility, or unsystematic risk, of the sector in comparison to the market as a whole. In this study, we explored the impacts on industry sectors due to climate risks through shocks applied to the beta values. The region-specific climate damage functions obtained in Section 4 are translated into shocks to the industry betas accordingly, so as to vary their volatility consistent with each scenario.

For example, in the No Mitigation scenario where agricultural productivity falls significantly due to global warming acceleration, the agriculture sectors in general are subjected to greater climate risks and hence volatility, resulting in significantly larger beta values. These shocks then propagate through sectoral equity performances and are used to provide clarity and comparison across countries and sectors, as well as between the sentiment scenarios, Two Degrees and No Mitigation.

Finally, within each market, the equity performance by industry (Table 9 and Table 10) is measured based on the notional Value-at-Risk (VaR), defined in this study as the drop in performance in the worst impacted quarter over the five year modelling period (i.e., the worst one of twenty quarters hence the notional 5th percentile).

	Sentiment Scenarios	No Mitigation		Two Degrees	
	Countries	Developed	Emerging	Developed	Emerging
Worst Performing Sectors	Real Estate	-36%	-38%	-19%	-24%
	Basic Material	-26%	-36%	-14%	-23%
	Construction	-26%	-31%	-14%	-20%
	Energy/ Oil & Gas	-24%	-77%	-13%	-51%
	Consumer Services	-20%	-44%	-11%	-30%
	Agriculture	-17%	-40%	-9%	-25%

**Table 9: Summarizing the top worst performing industry sectors across both developed and emerging economies**

	Sentiment Scenarios	No Mitigation		Two Degrees	
	Countries	Developed	Emerging	Developed	Emerging
Best performing sectors across	Transport	-17%	-27%	-9%	-17%
	Agriculture	-17%	-40%	-9%	-25%
	Consumer Retail	-20%	-26%	-11%	-18%
	Health Care	-21%	-23%	-11%	-15%
	Industrial/ Manufacturing	-25%	-26%	-13%	-16%
	Technologies (Renewables)	-21%	-27%	-11%	-16%

**Table 10: Summarizing the top best performing industry sectors across both developed and emerging economies**

The top 3 worst performing sectors are the same in both scenario variants, which shows that systematic effects dominate over the short-term (i.e. economy wide effects) (Table 9).

In the developed economies, the worst performing sector is Real Estate, closely followed by Basic Materials, Construction and Industrial Manufacturing. While in the emerging economies, the worst performing sectors are Energy/Oil and Gas, Consumer Services and Agriculture. According to the Modern Portfolio Theory, it is possible to hedge risk by switching investments to Consumer Retail in both Emerging and Developing markets in the No Mitigation Scenario, and to Technologies (Renewables) for the Two Degrees scenario (Table 10).

The box plots on the following page represented by Figure 13 to Figure 16 show the distribution of returns for each sector.

For example, in Figure 13, the “box and whiskers” representing Real Estate is built from the 20 quarterly return figures for the Real Estate sector in the No Mitigation Scenario, with the top and bottom of the range representing the best and worst quarterly return figures, respectively, over five years. We define the bottom of the range as “notional VaR”. Figure 13 and Figure 15 represent the US (indicating the developed economies) while Figure 14 and Figure 16 are for China (indicating the emerging markets).

In the developed countries, Real Estate represents the most impacted sector for both No Mitigation and Two Degrees scenario. However, the notional VaR for Real Estate in the No Mitigation scenario is -35% while the notional VaR for the Two Degrees scenario is -20%.

This analysis shows that heavy users of fossil-fuel resources are most vulnerable to any movements in fossil fuel prices. Thus, it is not surprising to note that Basic Materials, Construction and Industrial Manufacturing are among the worst performing sectors in the No Mitigation scenario, especially in developed markets, ranked in terms of VaR.

Another sector worth emphasizing is the Energy/Oil and Gas sector, which is among the worst performing sectors in emerging markets for both sentiment variants. In the No Mitigation scenario, there is a preference for higher energy demand dominated by fossil fuels, leading to a decrease in volatility for energy stocks over time. Energy stocks are relatively more volatile in emerging markets than developed ones, resulting in amplified losses when equity indices relatively underperforms when economic shocks are applied. Hence, even though energy stocks better perform in developed markets, these stocks are generally underperforming when compared to the rest of the sectors.

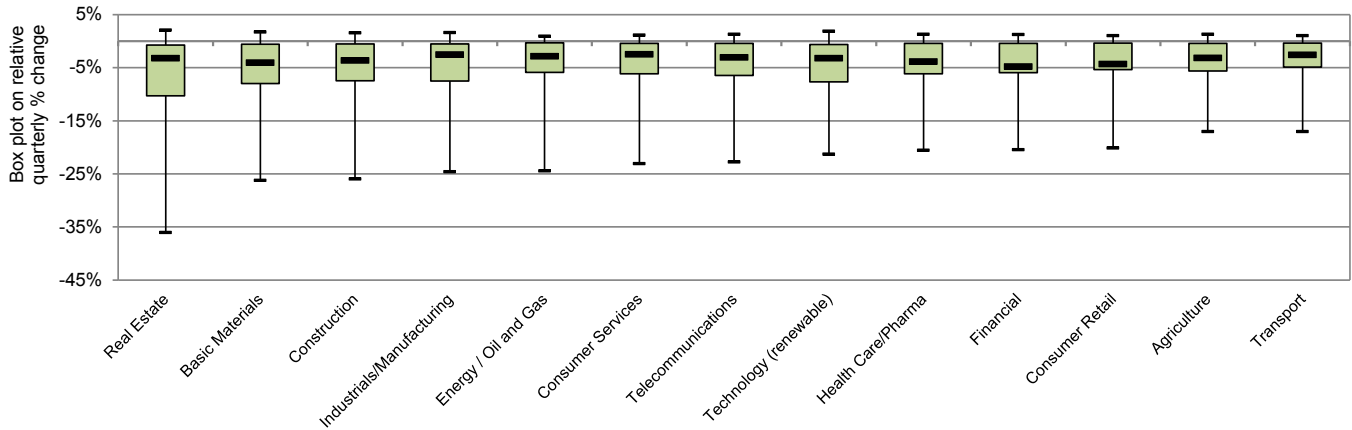


Figure 13: US market equity performance across industry sectors – No Mitigation scenario

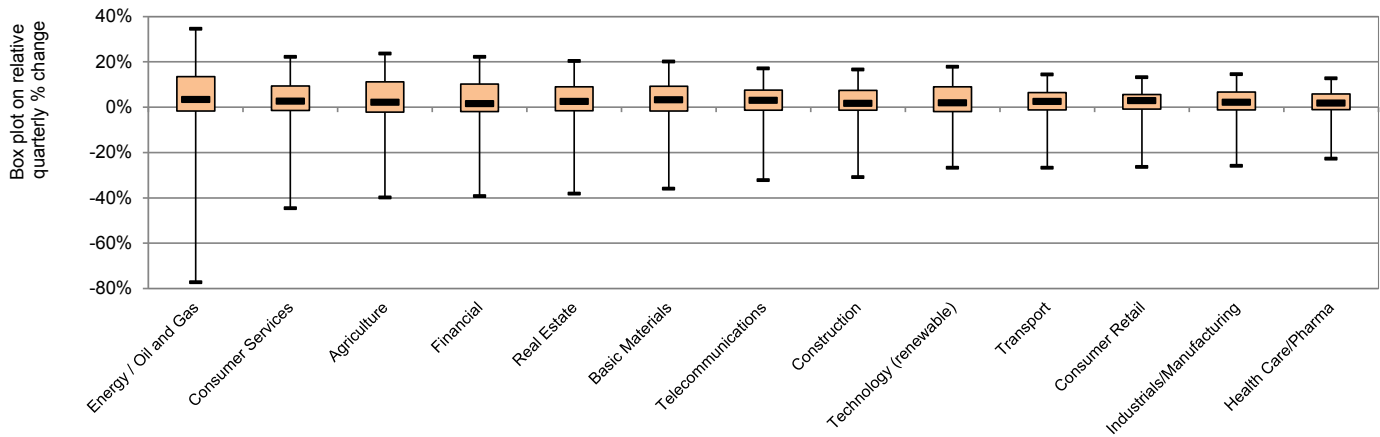


Figure 14: China market equity performance across industry sectors – No Mitigation scenario

**Financial conclusions**

Our analysis enables us to quantify the impact of climate risk scenarios on different asset classes, industries and regions. In particular, we can assess to what extent standard portfolio reallocation would enable investors to shield themselves from different scenarios of climate risk.

The analyses across sectors in developed and emerging markets (Figure 20 to Figure 23) reveal the hedging potential of cross-industry diversification and investment in sectors with low climate risk.

We find that under No Mitigation, the worst case scenario, it is possible to cut the maximal loss potential by more than 50% by shifting from Real Estate (in developed markets) and Energy/Oil & Gas (in emerging markets) towards Transport (in developed markets) and Health Care/ Pharma (in emerging markets). This implies that approximately half of the returns impacted due to climate change can be hedged through cross-industry and regional diversification. Interestingly, we find a similar magnitude for the hedging potential of different portfolio allocations.

Table 14 and Table 15 consider the notional VaR and long-term impact by portfolio structure for each scenario. We can infer that, under the No Mitigation, 51% can be hedged by shifting from more equity-loaded portfolios (Aggressive) to a fixed income-heavy portfolio (High Fixed Income). Comparing this to the longer-run performance of the portfolio, the hedging potential across portfolio structures reveals that portfolio managers stand to gain up to 25% by shifting from a high fixed income investment to an equity-loaded structure (Aggressive) under Two Degrees.

An investment manager wishing to hedge climate risks for both Two Degrees and No Mitigation scenarios is advised to adopt the High Fixed Income portfolio containing assets from developed markets as although long-term returns are low, downside losses are minimised. In the event of a Two Degrees scenario, there is little opportunity to hedge downside climate risk through portfolio construction.

In this scenario an Aggressive portfolio offers the best returns over the long term. In the event of a No Mitigation scenario, the High Fixed Income scenario offers the best protection against downside risk and also offers the best long term performance.

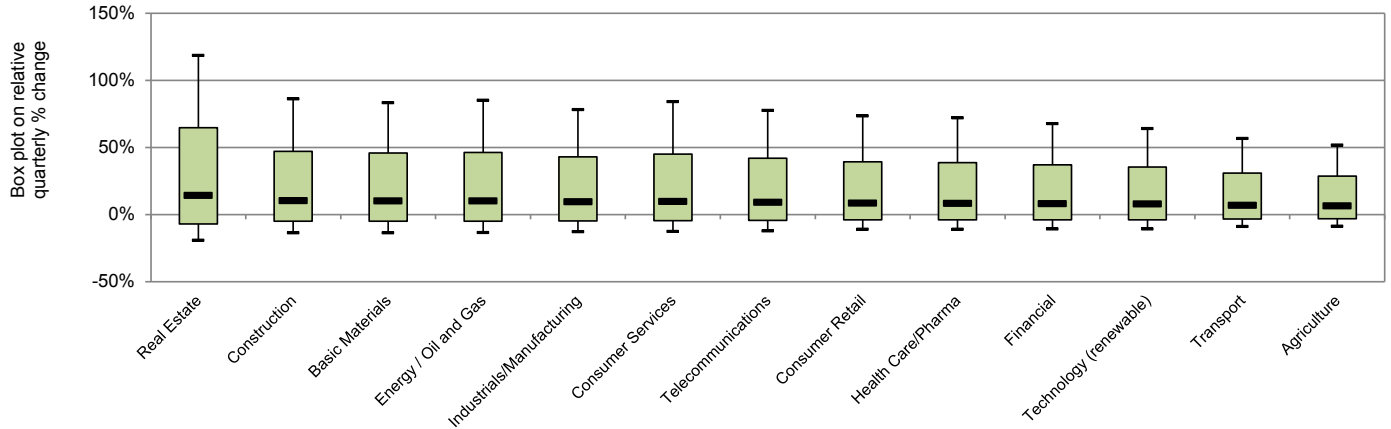


Figure 15: US market equity performance across industry sectors – Two Degrees scenario

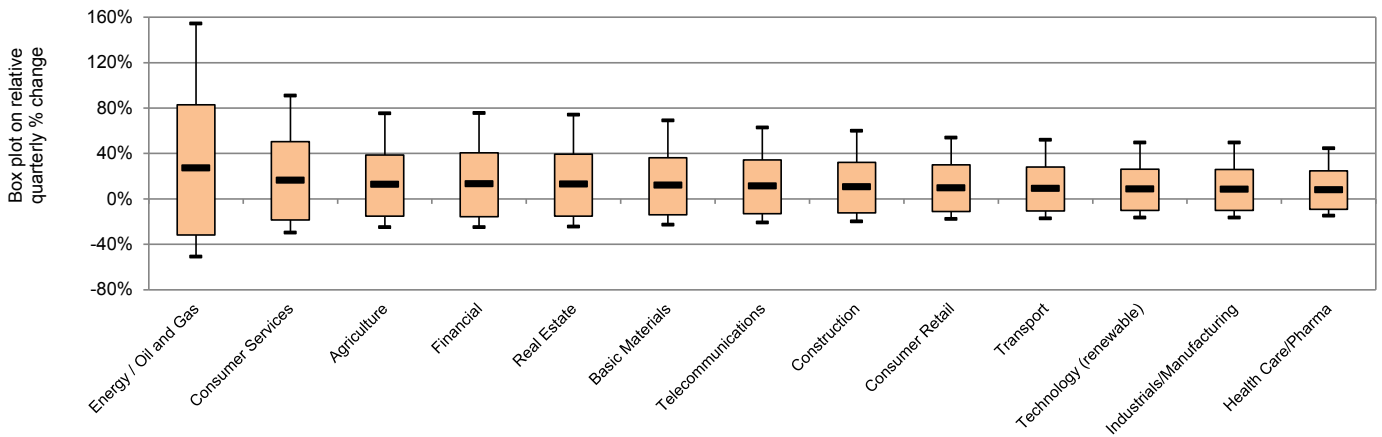


Figure 16: China market equity performance across industry sectors – Two Degrees scenario

Portfolio Structure	Baseline	Two Degrees	No Mitigation
High Fixed Income	0	-10%	-23%
Conservative	1%	-11%	-36%
Balanced	1%	-11%	-40%
Aggressive	1%	-11%	-45%

Table 11: Summary of portfolio performance measured by the 5% VaR by structure and scenario, nominal %

Portfolio Structure	Baseline	Two Degrees	No Mitigation
High Fixed Income	4%	-3%	-4%
Conservative	12%	9%	-26%
Balanced	16%	17%	-30%
Aggressive	21%	25%	-45%

Table 12: Summary of portfolio performance (long-term impact after 5 years) by structure and scenario, nominal %

## 8 Conclusion

This ground breaking research has quantified the implications of climate risk on investment portfolios over the short-term. As far as we are aware, research addressing this question has not yet been attempted.

Previous studies look at the direct physical effects of climate change over the long-term, typically in the second half of this century, when the effects of climate change have already started to have major impacts. These studies then discount the future impacts of climate change to give a net present value. However, financial markets could be affected much sooner and greater, as market sentiments may alter as new information comes to light about the effects of climate change.

The innovative approach adopted in this research allowed us to simulate ‘what-if’ scenarios over the next five years. This required the development of a scenario stress-testing framework that allowed us to consider how markets may behave over the short-term under different IPCC climate trajectories. The effects of climate change on markets will be driven by the projections of likely future impacts, new technology, changing regulation, indirect climate change impacts and shifting market sentiment.

The scenarios we developed are coherent, highly unlikely yet still plausible, quantifiable narratives that describe how expectations about future climate trajectories may have an impact on economic and financial markets over the next five years. This study therefore quantifies the potential financial impacts of a shift in market sentiment driven by significant changes in investor beliefs about the future effects of climate change.

In the short-term, these risks pose a significant threat to investment portfolio performance. Through the analysis of two opposing climate risk scenarios, both have short-term negative impacts on the global economy and investment portfolios.

In the worst-case No Mitigation scenario, a global recession occurs during the first three quarters of the shock and the global economy never recovers, losing an estimated 16% of cumulative economic output by 2050.

In the alternative scenario, action to limit warming below 2°C will have negative short term costs lowering economic output for over a decade when compared to baseline. But the long term benefits make the transition worthwhile, increasing aggregate output to 2050 by up to 4.5% above baseline levels.

Investors are therefore encouraged to take a long-term perspective when considering climate risk on investment portfolios.

Nevertheless, investors cannot entirely protect themselves from the exposure to climate risk. Although we have shown that roughly half of the returns from impacts due to climate change can be respectively hedged through cross-industry and portfolio construction, these two “halves” are not cumulative such that no one strategy is able to offer more than 50% coverage of “hedgeable” risk.

Climate risks therefore will remain an aggregate risk driver that requires system-wide action to mitigate its economy-wide effects.

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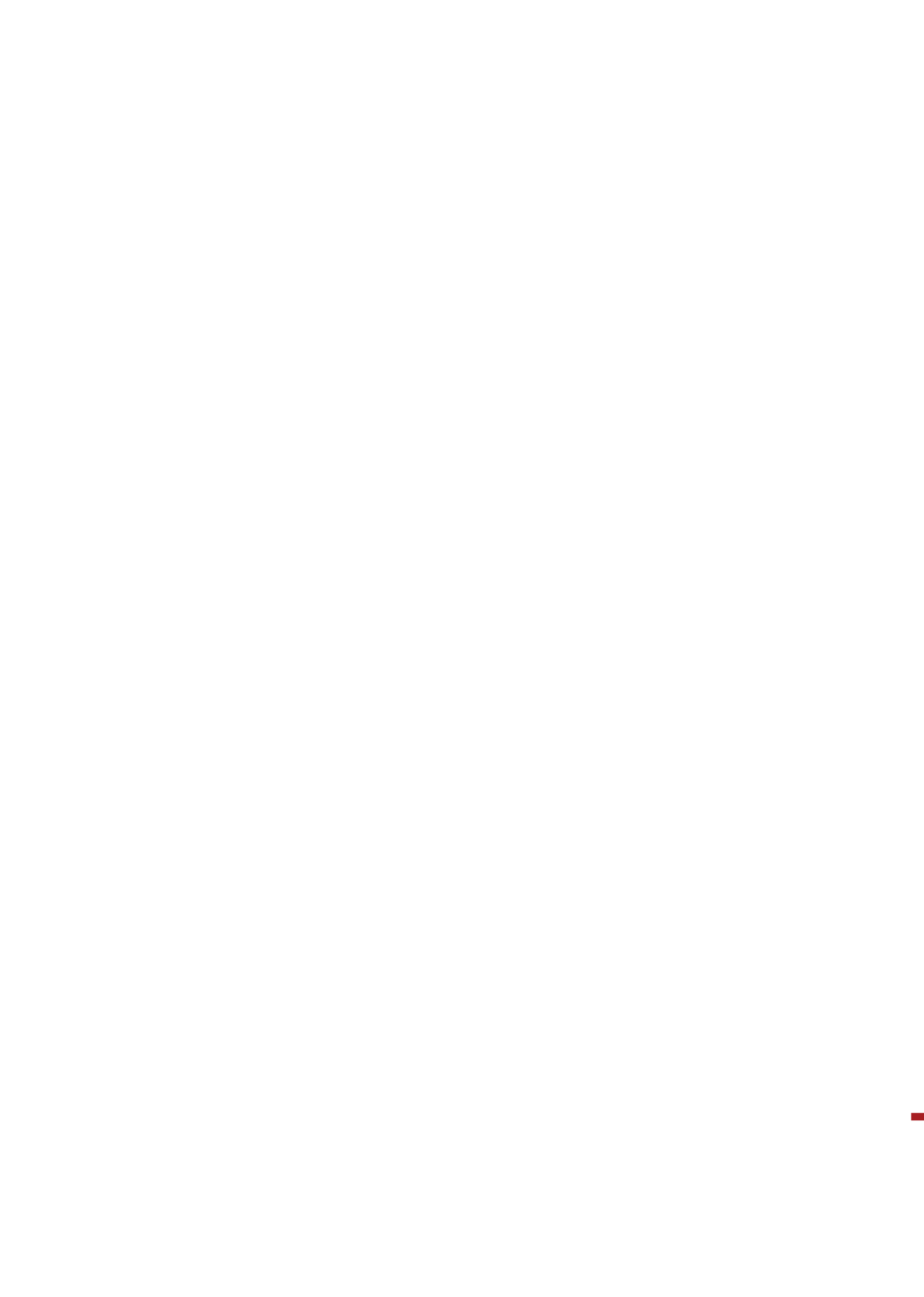
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## Appendix A - Summary of climate risk reports

Year	Report	Contributor(s)	Nature of Contributor
2015	<i>Investing in a time of Climate Change</i>	Mercer	Global Investment Consultant
2015	<i>From boom to bust? Climate risk in the golden state</i>	Risky Business Project	Economic Research Firm
2015	<i>Responding to Climate Change Risk in Portfolio Management</i>	Schroders	Asset Management Company
2014	<i>Climate Change is a Global Mega-Trend for Sovereign Risk</i>	Standard and Poor's	Financial Services Company
2014	<i>Managing Climate Risks to Well-Being and the Economy</i>	Committee on Climate Change	Independent advisory to the UK Government
2014	<i>Asset Allocation Survey: European Institutional Marketplace overview</i>	Mercer	Global Investment Consultant
2011	<i>Climate Change Scenarios – Implications for Strategic Asset Allocation</i>	Mercer	Global Investment Consultant
2005	<i>Framing Climate Risk in Portfolio Management</i>	Ceres and World Resources Institute (WRI)	Non-profit organisations
2015	<i>The cost of inaction: Recognising the value of risk from climate change</i>	The Economist Intelligence Unit	Popular Economic Journal

**Table 13: Summary list of climate risk-related research papers and reports**



**Report citation:**

Kelly, S., Yeo, J.Z., Coburn, A., Copic, J., Crawford-Brown, D., Foley, A., Neduv, E., J., Ralph, D., Saidi, F., 2015, *Unhedgeable Risk: How Climate Change Sentiment Impacts Investors*. University of Cambridge.

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