Climate Scorpion
– the sting is in the tail
Introducing planetary solvency

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www.actuaries.org.uk

March 2024

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Cover: *Graph reproduced from 'The extreme scenarios – massive or only little warning – are unlikely but possible. This is what we mean by "tail risk"' from Emanuel, Kerry A. Climate Science, Risk & Solutions. Massachusetts Institute of Technology, 15 May 2020: https://climateprimer.mit.edu/climate-science-risk-solutions.pdf Original graph credited to Chris Hope, University of Cambridge. The graph is reproduced with permission via Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International license (CC BY-NC[1]SA 4.0)*

Professor Johan Rockström

Director Potsdam Institute Climate Impact Research

This report shows how important it is for us to collaborate across disciplines on climate change. It re-emphasizes how important it is to treat 1.5°C as a physical limit and not a political target, recognizing the risk from tipping points. Four of these are showing scientific evidence of now being at risk already at 1.5°C, really putting humanity's future at risk. This is a planetary crisis which we must address with co-ordinated policy action to accelerate the energy transition.

Julius Pursaill

CIO, Cushon

This examination shows that commonly used net zero carbon budgets are based on unrealistic assumptions giving poor odds of limiting warming, the chance of failure is much higher than the chance of losing Russian Roulette, which we would not accept in many endeavours. Rigour and prudence are required to improve the transparency of assumptions alongside immediate action to improve our odds.

Mike Clark

Director, Ario Advisory

Policy sets the guardrails for society within which capital and innovation flow. This report makes it clear that current energy policies are not sufficient to meet Paris Agreement goals and the very high risks associated with failure. It provides impetus for immediate and far-sighted policy decisions that are required to accelerate the positive tipping points of the energy transition, helping economic growth and securing a biosphere that will support future human prosperity.

Ruth Richardson

Executive Director, Accelerator for Systemic Risk Assessment

Faced with multiple, interconnected, and compounding crises in global systems, our current risk management toolkit struggles to cope with this complex dynamic, increasing the risk of failure and disruption from these intersecting crises. Policy- and decision-makers all around the world need to start radically rethinking their approaches to risk assessment and response. It's encouraging to see this new report from the IFoA, including its recommendation for a Planetary Solvency framework.

Dr Nicola Ranger

Executive Director, Oxford Martin Systemic Resilience Programme, University of Oxford

The message of this report is simple – we need a realistic risk assessment of climate change and we need to act on it. It reminds us not to forget the 'sting in the tail' of climate impacts or we may risk 'planetary insolvency'. This reflects two things. Firstly, climate change will lead to transformative changes in the core systems we depend on, driving cascading risks - our research, for example, shows a "green scorpion" of nature-related feedbacks well in excess of $5 trillion in losses. Secondly, most supervisors and financial institutions are not considering these risks within their risk management, flying blind and leaving the financial system dangerously unprepared.

Dr James E Hansen

Climate Science, Awareness and Solutions, Columbia Climate School

The sting is in over-reliance on climate models. Earth's history shows that real-world climate sensitivity is in the models' tail.

Simon Sharpe

Author of Five Times Faster, Rethinking the Science, Economics and Diplomacy of Climate Change

Too often, the long-term impacts of climate change are described in terms of central estimates, when rule number one of risk assessment is to focus on the worst case. Governments should have full risk assessments for climate change just as they do for threats to national security or public health. This is not about the psychology of science communication to individuals; it's about the proper processing of information through institutions.

Julie Baddeley

Chair, Chapter Zero

This report helps NEDs appreciate the radical uncertainty that climate change brings into the boardroom. It raises the concern that we may have badly underestimated global warming, underlining the importance and urgency of delivering emissions reductions. Boards need to understand these messages, so they can assess whether current risk management processes are credible, how companies are positioned to deal with the implications of radical climate uncertainty and whether company strategy is sufficiently nimble to capture the opportunities.

Jennifer Stott

IFoA Sustainability Board Deputy Chair

This is an important report which focuses our attention on high levels of uncertainty in Earth System models. These in-turn impact the relationship between carbon budgets and temperature goals, crucially showing that carbon budgets need to be smaller. This classic model risk problem implies an urgent need for financial services firms to carefully examine their net zero approaches and the assumptions underlying carbon budgets.

Actuaries and other model users in financial services need to understand this so they can be clear, particularly when communicating their findings to stakeholders or clients, on the limitations of climate change models.

Nick Spencer

Past Chair, IFoA Sustainability Board

Systemic risks, including climate change, are multiplying and intensifying, with their tipping points posing the threat of irreversible harm. Systemic risks and their interconnectedness pose fundamentally different challenges that need to be embraced and not treated as ignorable inconveniences. Traditional risk management approaches simply don't recognise these characteristics. There is a need to embrace complex risk analysis to help us navigate systemic failure and the disruption from these connected crises.

Foreword – the actuarial approach to climate risk

Professor Timothy M. Lenton
Chair in Climate Change and Earth System Science, University of Exeter

Dr Luke Kemp
Senior Research Associate, Notre Dame Institute of Advanced Studies, University of Notre Dame

Actuaries deal with uncertainty and extreme risks every day.

They work with ruinous events for individuals (accidental death) and businesses (bankruptcy). These are severe, uncertain and irreversible threats. Climate risk is similar: it is highly uncertain, will likely entail irreversible shocks, and might even be ruinous, either for nations or even the world. Actuaries take extreme risk seriously and have developed practical tools for managing it. Unfortunately, their approach has rarely been applied to climate risk. This timely report seeks to address this.

'Climate Scorpion – The Sting is in the Tail' puts forward the case for why and how the actuarial approach can be used for climate change. It begins by outlining how actuaries deal with extreme, ruinous risks, what this means for climate change, what we do and don't know about the physical impacts, tipping points and social knock-on effects of climate change, and what actions we can take to manage the risk. In particular, these actions include policy action to accelerate positive socio-economic tipping points such as the take-up of renewable energy.

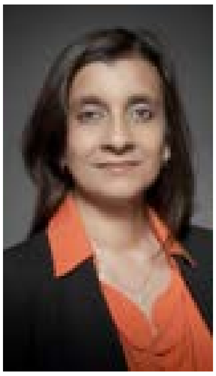
It compellingly argues that we should view climate risk as a problem of 'Planetary Solvency', understanding and managing risks to the long-term survival of global society. In short, we need to have a best guess about the worst-case and make policy on that basis. This is a much-needed concept, and the idea of a Planetary Solvency commission is a welcome one. Especially given our growing, yet precarious, lack of knowledge about extreme climate risk and tipping points.

This report is an initial step rather than a definitive end. It hopefully marks the beginning of more intense and fruitful engagement of the actuarial profession with global climate risk. After all, the pensions and insurance industries, supported by actuaries and other financial services risk professionals, must be part of any planetary solvency management plan.

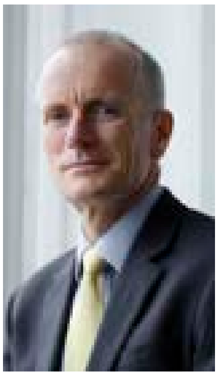
...we need to have a best guess about the worst-case and make policy on that basis.

Introduction

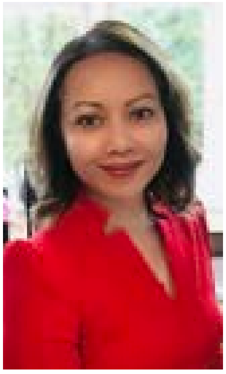
The IFoA Presidential Team



Kalpana Shah
President, Institute and Faculty of Actuaries



Matt Saker
Immediate Past President



Kartina Tahir Thomson
President-elect

2023 was the hottest year on record with the global average temperature 1.48°C[1] above pre-industrial levels. The increasingly severe impacts of climate change are felt by billions. Alongside highly disruptive physical changes, there are significant implications for the economy and the financial system – and this is just the beginning.

Despite huge progress on climate solutions, such as renewable energy and electric vehicles, levels of atmospheric greenhouse gases continue to rise, which will drive further warming. We are fast approaching the 1.5°C global temperature target and need to take rapid action, supported by long-term policy decisions, to accelerate positive socio-economic tipping points to avoid breaching 2°C.

In this report, the third in our collaboration with scientists on global warming, we build on previous reports on climate change tipping points and climate scenarios to explore in detail two critical questions:

- **How much hotter will the world get and by when?**
- **What are the implications for society and how do we manage these risks?**

Actuaries cannot predict the future, but at the core of our expertise is analysis of data to understand the range of uncertainty around future assumptions, considering the risks and worst-case scenarios. Our advice informs the level of activity and urgency required to avoid them. We explore scenarios that could have the greatest impact, even if the probability is low or cannot be readily quantified. We are concerned with protecting against the 'risk of ruin'. Reverse stress testing is a process where actuaries think about circumstances that would cause insolvency, so that they can take action to avoid this. This approach can valuably be applied to climate change. As well as thinking carefully about what to expect and sources of uncertainty, we can also explore the 'risk of ruin', the point beyond which our global society could no longer successfully adapt to climate change. We coin the phrase **'Planetary Solvency'** to explore how society could adapt actuarial techniques to manage these risks more effectively.

We concluded in our previous reports in this series[2] that there has been limited consideration of the severity of the impacts our global society could experience under the worst-case scenarios. This latest report looks at the current trajectory of global warming and the possibility that Earth's climate may be more sensitive to elevated concentrations of greenhouse gases than we thought. Credibly assessing 'the sting in the tail' and the full range of potential impacts allows policymakers to understand just how high the stakes might be, informing long term policy actions that can be taken to mitigate or avoid them.

Actuaries have played a significant role in enabling critical societal services such as pensions and insurance to allow society to function in the short and long term. We want pension schemes to be able to pay out pensions many years into the future. We have an equally important responsibility now to play an active role in addressing the sustainability challenge. Our long-term thinking, financial system understanding, risk management mindset and probabilistic reasoning combine powerfully to complement climate science and communicate risks clearly to regulators and policymakers.

Key findings

> *"Our world knows not what it is gambling with, and if we don't control this fire, it will burn us all down"*
>
> Mia Mottley[3]

We put forward five key findings based on the latest climate research. The implications of these are profound.

I: The rate of global warming accelerated in 2023 - There is early indication this is not temporary

The rate of global warming accelerated in 2023. Scientists are not yet sure what is the cause, and therefore do not know how much of this is a temporary fluctuation or permanent change.[4] If this is a permanent change, it reduces the time available to reduce emissions.

II: Life in the tail - Increased warming is now driving more severe impacts across the planet

Climate change has arrived, with severe impacts emerging at lower temperatures than expected. The distribution has shifted; historic tail risks are now expected. Climate risks are complex, interconnected and could threaten the basis of our society and economy. A systems approach is required to consider how connected risks might increase societal impacts. Even without considering cascading impacts, there is a 5% chance of annual insured losses of over $200 billion in the next decade, with total (insured and uninsured) economic losses breaching the $1 trillion mark.

III: An overshoot of the 1.5°C temperature threshold is likely

There is an increasing disconnect between current net zero carbon budgets and the 1.5°C temperature goal, with several scientific agencies reporting that levels of global warming in 2023 were close to or already at 1.5°C. An overshoot of the 1.5°C temperature goal by 2030 is increasingly likely and current net zero carbon budgets give a low probability of limiting temperature. We need to re-calibrate carbon budgets, given uncertainty and experience to date.

IV: The sting in the tail of the Earth's climate sensitivity

The Earth's climate may be more sensitive than we thought, meaning the planet may warm more quickly than expected for a given level of greenhouse gases. This would reduce carbon budgets. It is unclear how much more warming we are committed to post 2030. This is uncertain due to many factors, including ice melt rate decreasing Earth's albedo, the impact of aerosol cooling, climate tipping points, and the pace of the energy transition.

V: Warming above 1.5°C is dangerous, increasing the risk of triggering multiple climate tipping points

Tipping points include the collapse of ice sheets in Greenland, West Antarctica and the Himalayas, permafrost melt, Amazon die back and the halting of major ocean current circulation. Passing these thresholds may constitute an ecological point of no return, after which it may be practically impossible to return the climate to pre-industrial (Holocene) stability. Tipping points may interact to form tipping cascades, that act to further accelerate the rate of warming and climate impacts.

Moving forward

Policymakers must act decisively to accelerate the transition with long-term policy decisions, informed by up-to-date information on climate change and comprehensive risk assessments. Our recommendations are to:

I. Carry out a realistic risk assessment of climate change as a matter of urgency, and act on it

II. Educate and take action on positive tipping points in the economic system

III. Develop a Planetary Solvency framework to support human prosperity, now and in the future

Climate change is intrinsically linked with many other global threats.

I: Carry out a realistic risk assessment of climate change as a matter of urgency, and act on it

A full risk assessment of climate change should be carried out in line with risk management best practices. This should take into account the full range of outcomes, including tipping points, realistic worst-case scenarios and the risk of ruin. This should be informed by a global warming ‘experience analysis’, up-to-date information on global warming, greenhouse gas levels, aerosol cooling and other material factors that may influence temperatures.

II: Educate and take action to accelerate positive tipping points in the economic system

Countries should invest in educating the public and policymakers about tipping points and realistic climate risk assessments.

Positive socio-economic tipping points can interact to drive rapid adoption of low-carbon technologies, with the right policy framework. This will be overwhelmingly positive economically, as it would mitigate the sting from climate-change tail risks, resulting in trillions of dollars of net savings.

III: Develop a Planetary Solvency framework to support long term policy decisions

Climate change is intrinsically linked with many other global threats. While this report focuses on climate change, the risk cascades we explore show that we need to develop a global and holistic approach to risk management. Risk management techniques from a variety of disciplines should be used to develop a global risk management framework that explores the interconnected societal, natural, climate and economic risks we face, and recommends actions to address them.

Planetary Solvency should be complemented with long-term governance and risk management. This could include radical actions to reduce global temperatures and govern large-scale displacement. These need to be undertaken carefully, democratically, and through holistic risk assessments, for example comparing the risks of unmitigated climate change versus geoengineering.

Financial Services Implications

Implications for financial services institutions include a need to re-visit carbon budgets and related assumptions, a need to consider whether and how to move away from temperature commitments to focus on decarbonizsation activity, ensuring their net zero approaches support real world decarbonization, and how to constructively support policy action to accelerate positive tipping points.

1: An actuarial approach to climate change

For over a century, actuaries have been quantifying investment, mortality and other risks in order to calculate life assurance premiums and reserving requirements to keep insurance companies and pension schemes solvent. In this section, we explore how these techniques might be applied to climate change and other extreme threats.

The actuarial approach to long-term financial solvency offers a logical framework to look at climate change. Where the regulatory regime for insurance protects consumers of insurance from the ruin of their insurer, a similar approach for greenhouse gas emissions should protect citizens from the ruin of their environment.

In this section, we summarise how actuaries support financial institutions to remain solvent over the long term, provide an explanation of tail risks and why they are important to consider, and explore how actuarial techniques could be applied to climate change.

Explainer: What is tail risk?

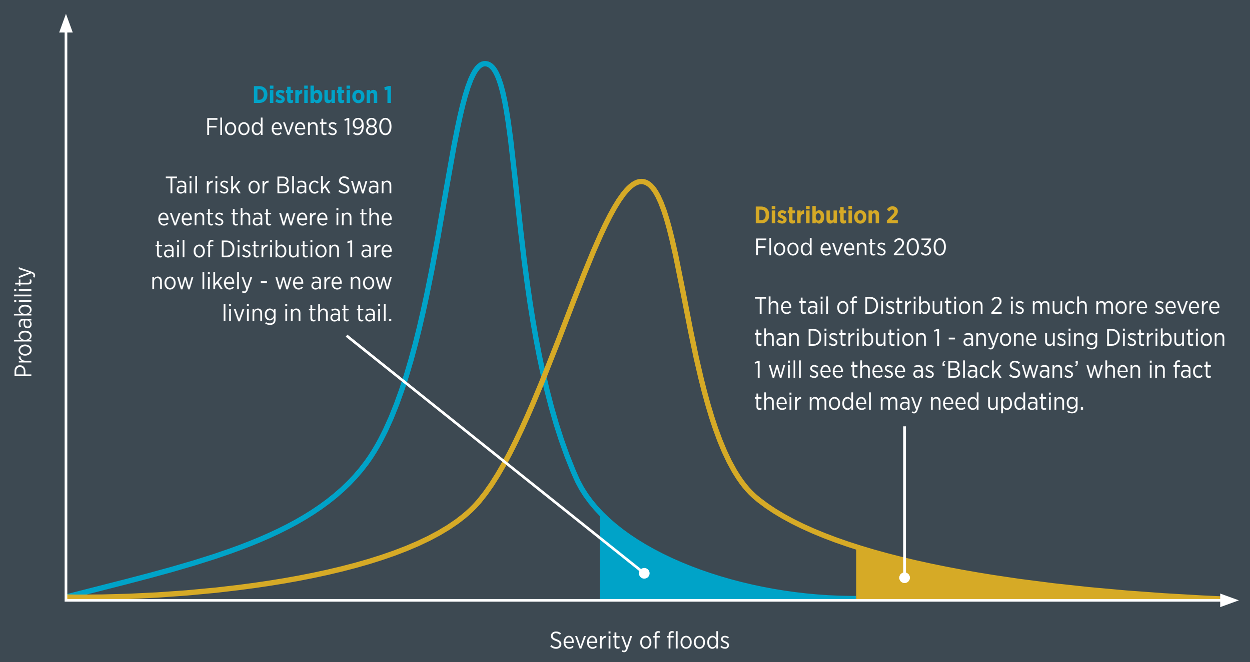
Tail risk refers to the risk of unlikely events occurring, typically in the 'tails' of a probability distribution. Such events can be rare but can have significant impacts on financial markets, investments or other systems. Actuaries often pay attention to tail risk as it involves the potential for large losses, which are of particular interest for risk management. The term 'black swan' is sometimes used to refer to an event that was not imagined within the range of modelled outcomes.[5]

As mathematical models are only an approximation of the real world, built on underlying assumptions, the actual probability of some events may be significantly higher than the probability estimated by the model. This may indicate a need to consider carefully the appropriateness of the model and the underlying assumptions, rather than labelling an event considered unlikely by the model as a tail risk.

For example, as the climate changes, the likelihood of severe flooding increases in some areas, meaning that events that were considered '1-in-100 year' events become more frequent, becoming 1-in-10 or 1-in-5 year events. Another way of saying this is that the probability distribution is shifting, meaning that events that were tail events in the past are becoming more likely. As well as the distribution shifting, the shape can change, with the tails becoming fatter.

This is illustrated in *Figure 1*, below. Suppose Distribution 1 represents flood events in England in 1980 and Distribution 2 represents flood events in England in 2030. Flood events that would have been unlikely, or in the tails of Distribution 1, are now much more likely to happen as winters are much wetter. Note these graphs are illustrative of the change in distribution, not actual data.

Figure 1: Tail risk and shifting distributions (illustrative)



1.1 How actuaries support financial institutions to remain solvent

Actuaries help financial institutions navigate risk and uncertainty in the short and long term. For example, a pension scheme needs to make decisions about how much money to put aside today and where to invest it, so that they can provide people with pensions in the future. Actuaries do this by attempting to explore the future. This requires making informed assumptions, such as how long people might live for and what stock market returns might be. Actuaries regularly review these assumptions using experience and expert judgment to test whether they remain appropriate.

As well as making 'best estimate' assumptions about the future, actuaries also consider sources of risk and uncertainty. Even if life expectancy increases or the stock market crashes, pension scheme members will still expect to receive their pension. Actuaries work with pension schemes to ensure that happens.

Actuaries have developed techniques for a range of risks, from low frequency/ high impact catastrophic risks (tail risks) to those covered by mass market products, such as motor and household insurance. These techniques include modelling systems failure, modelling both natural catastrophes (e.g. hurricanes, flooding) and man-made catastrophes (e.g. terrorism), modelling scenarios (such as a run of claims and stock market crashes undermining an insurance company), and undertaking holistic risk assessments for banks. These risk assessments inform management about actions to take to manage risk, both in the short and long terms.

In the insurance sector, risk assessment by actuaries is based, in part, on understanding scenarios that could have the greatest impact, even if their probability is low. Capital modelling for insurance companies, which estimates the reserves that need to be held to ensure insolvency is avoided, typically looks at extreme events that might occur. The graph below *(Figure 2)* sets out a stylised example of a probability distribution for an insurance company's claims and the kind of shape you would expect – somewhat skewed towards the right tail.

An extremely bad or 'ruin' scenario for pension schemes or insurance companies is where liabilities (losses) exceed assets (reserves) and insolvency occurs. As shown in *Figure 2*, the capital required to cover a ruin scenario sits far out to the right in the tail of the distribution, well above the level of claims the insurance company might expect on average. The approach is conservative[6] and designed to protect shareholders and policyholders alike. This all occurs under a wider regulatory framework which aims to protect citizens by ensuring pension schemes and insurers do not fail.

Explainer: Model Risk

One of the risks that actuaries take into account is 'model risk' which can be defined as 'the risk that the use of a model will lead to an incorrect decision'. Model risk is a broad term but can be ascribed to three major causes, which are:

- The wrong model has been used
- The model has been incorrectly implemented
- The model has been incorrectly used/ interpreted

As a model is a **representation of reality**[7], results from a model tell you about the model, not directly about reality. So when interpreting model results, there is always a step to move from the model to reality. Expert judgement is needed to build models, just as it is needed to move from model to reality, or **'escape from model land'.**[8] Model risk arises from the unavoidable mismatch between the real world system being modelled and the computer model used to represent it, which can lead to probabilities of adverse events being estimated that are materially different from real-world probabilities.

For risk management purposes, an estimated probability that is lower than the real probability is a bigger problem than probabilities that are too high. Actuaries working in risk management are conscious of this, and tend to be conservative in making choices when model-building and estimating. 'Conservative' to a risk manager means biased high, which can have the opposite meaning in science. A rule of thumb for risk modelling is that when uncertainty is high, simple models tend to be more helpful than complicated ones. This is because, if the model output depends upon assumptions that are used when building it and those assumptions are uncertain, the model output will tell you more about the assumptions than the real world. Sense checking for plausibility of model output is an essential step to mitigate model risk.

If we approach climate change from the perspective of financial solvency, the goal would be to limit the probability of a very bad outcome to an acceptably small value. In other words, the tail of the probability distribution would drive climate change policy, and the first question would be "how bad could it get"? This is the question that is asked when an insurance company models its capital requirements. An insurance company needs to be able to withstand the uncertainty of severe events. Under the European Solvency regime, the probability of failure is set at 0.5% or, put another way, insurance companies are required to hold enough capital to survive an unlikely but possible 1-in-200 year set of adverse events. Society as a whole might reasonably expect a similar standard for climate change and other risks that are faced.[9]

In *Figure 2* opposite, the 'mean' outcome indicated by the left vertical line shows the weighted average of the losses of all scenarios modelled. This may be a sensible estimate to use as the basis of setting insurance premiums, but not as a basis for protection against insolvency.

At the '1 in 200' level, 99.5% of outcomes result in a smaller damage level and only 0.5% (i.e. 1/200) are greater. Insurance companies hold capital to protect against loss arising from all causes at this level of probability under Solvency II. This is intended to assure their solvency except in the event of extreme losses on their insured portfolio.

Figure 2: Hypothetical Probability Distribution for Insurance company loss amount

1.2 Applying the actuarial approach to climate change

To apply this actuarial approach to climate change, we would need to derive:

- A set of most likely and worst-case outcomes, such as for the magnitude and rate of warming
- A set of ruin scenarios which would explore how climate risk could lead to societal ruin
- A set of temperature thresholds and determinants of societal fragility under climate stress

It would also be important to derive an acceptable probability of ruin in relation to climate change. If one insurance company fails, this would not impact all of society, whereas there is a level of global warming that may be practically challenging to adapt successfully to. This suggests that an even lower chance of failure than the 1-in-200 level set for insurance companies would be prudent.

Carrying out this analysis in a rigorous, dispassionate and meticulous way would provide guidance on the risks of climate change which could be used to inform long term policy decisions. In the following sections, we demonstrate how such an approach could be developed. We demonstrate how actuaries might approach deriving values for the rate and amount of warming in Section 2, as well as explore how the distribution has shifted for climate impacts over time. In Section 3 we explore a number of key risks that may occur at higher degrees of warming, which would influence the answer to the question, "beyond what temperature is successful adaptation unlikely?"

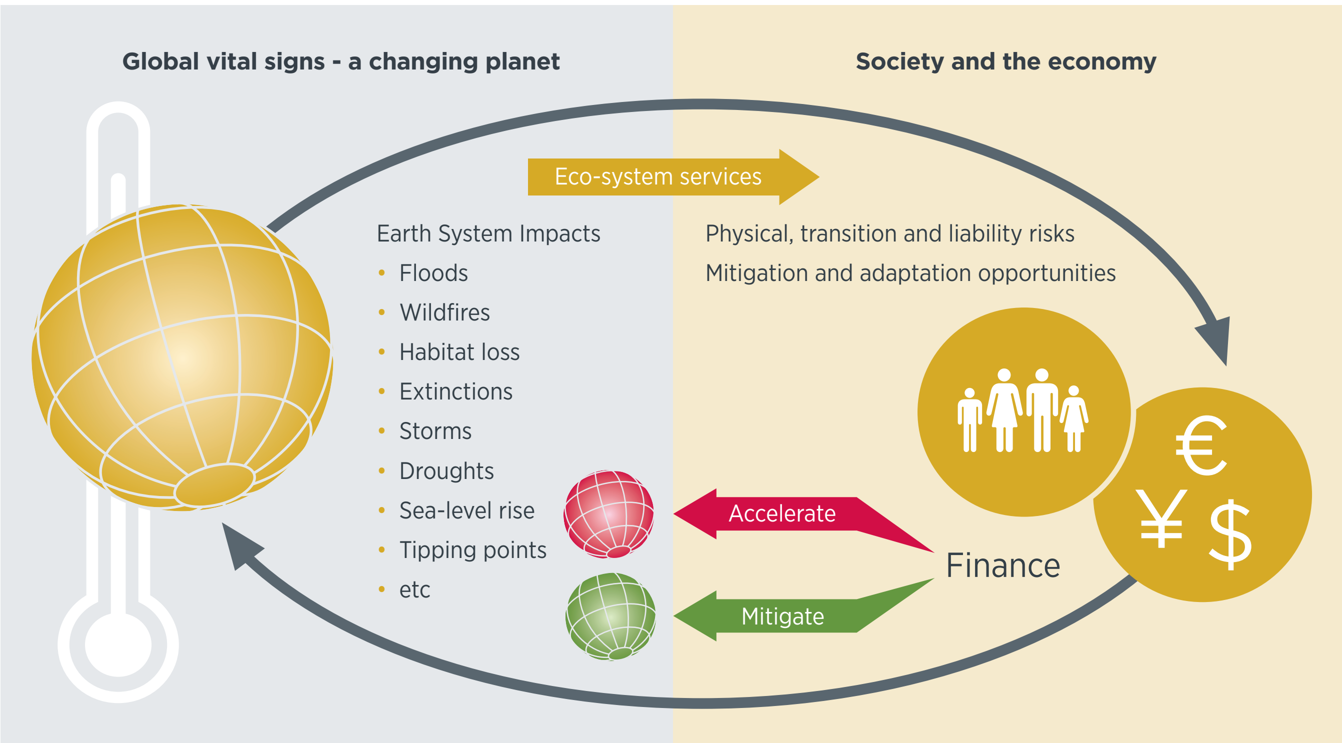
1.3 Introducing the Planetary Solvency concept

In Section 4 we provide a series of recommendations, including the development of a Planetary Solvency framework that would leverage financial services risk management techniques to assess and communicate risks more effectively to policymakers, supporting long-term policy decisions.

Planetary Solvency would combine nature, climate and societal risk assessments, leveraging the planetary boundaries[10] framework to assess risks to ecosystem services and thus society and the economy. Planetary Solvency recognises that *"society needs to be viewed as part of the biosphere, not separate from it"*[11] and that *"our society runs on energy and materials"*[12] rather than labour and capital.

The authors suggest developing the Planetary Solvency framework in a future, separate report. At a high level, a Planetary Solvency assessment would view nature as an asset[13] that provides ecosystem services to society, such as the provision of raw materials for our economy, the provision of food and regulating services like climate regulation. The authors view these ecosystem services as the flows from nature (the asset) that provide the essentials that society requires in terms of food, water, a stable climate, and so on. Just as financial solvency assessments assess the ability of a financial entity to pay claims now and in the future, Planetary Solvency would assess the ability of nature to continue providing the ecosystem services that underpin our society, both now and in the future.

Figure 3: Human society and economy rests on nature



2: The sting in the tail – expected warming, extreme events, climate overshoots and uncertainty

In this section, we explore the difficulties in estimating the future rate of global warming, and the risk that the rate of warming could be faster than currently projected.

Climate risk impacts are increasing globally, the distribution is shifting and what used to be tail risks historically are now becoming more frequent. There are more stings and they are more painful. Given the increasing risk above 1.5°C of warming, it is reasonable to suggest that our tolerance of it should be extremely low and that we should view this as similar to a solvency ratio for society – a level we must make every effort not to exceed for long.

Mitigating these risks and delivering a stable climate for future generations will require us not only to reduce emissions but also to remove greenhouse gases from the atmosphere, using both technological and natural solutions that are not yet proven at scale.

Explainer: The global warming experiment, what might the future hold?

Global warming is driven by the concentrations of greenhouse gases (GHGs) in the atmosphere, which are increasing due to human activity. The greenhouse effect means that there is more energy coming in (absorbed sunlight) than energy going out (heat radiated to space). This is referred to as Earth's energy imbalance.[14] Even if we reduced emissions to zero today, because of the level of GHGs already in the atmosphere, warming would continue until the Earth reaches thermal equilibrium, i.e. a state where energy absorbed from sunlight is equal to heat radiated back out to space.[15] However, there is uncertainty in how quickly the planet will warm (Earth's transient climate response to cumulative emissions (TCRE)) and the final temperature that would be reached (Equilibrium Climate Sensitivity (ECS)), which makes predicting the final equilibrium temperature challenging.

A simple analogy is to think of the planet as an electric oven and the level of GHGs in the atmosphere as the temperature setting. If we increase GHG levels, we are turning up the temperature, but it takes time for the oven to come up to temperature. However, the markings on the temperature setting are unclear; we simply do not know with certainty how much warming will be experienced for a given level of GHGs. Nor can we be sure about how fast the planet might warm. It's a bit like cooking in an old oven for the first time but with planetary consequences. In this section we explore some of the main factors driving the uncertainty and the implications of this.

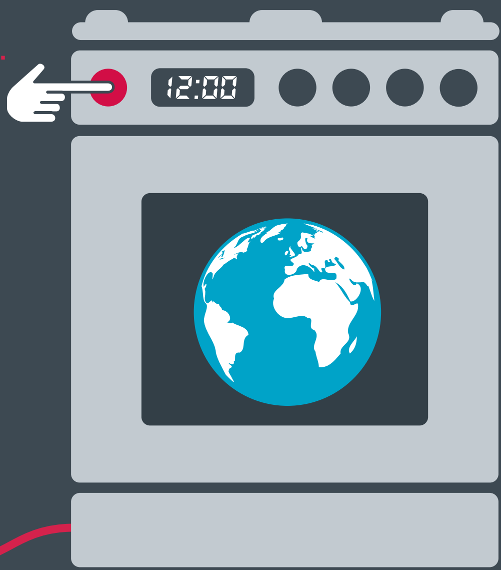
Figure 4: A planetary cooking experiment with global consequences

1. Greenhouse gas levels are the hand on the temperature setting.

As GHGs increase in the atmosphere, more energy is retained by the earth than is radiated back out to space, causing warming.

2. Earth's Energy Imbalance is the current.

GHGs levels increase the current - this is called Earth's Energy Imbalance (more coming in than going out)



3. Equilibrium Climate Sensitivity (ECS) is the temperature gauge.

ECS is like the markings on the temperature control. It's as if they have been rubbed away - we have some idea but there is significant uncertainty.

4. Carbon budgets are the timer.

Carbon budgets are like the timer - leaving the oven on for too long will burn the cake. But if we're not sure how accurate the temperature gauge is, that means we are also not sure about the carbon budgets.

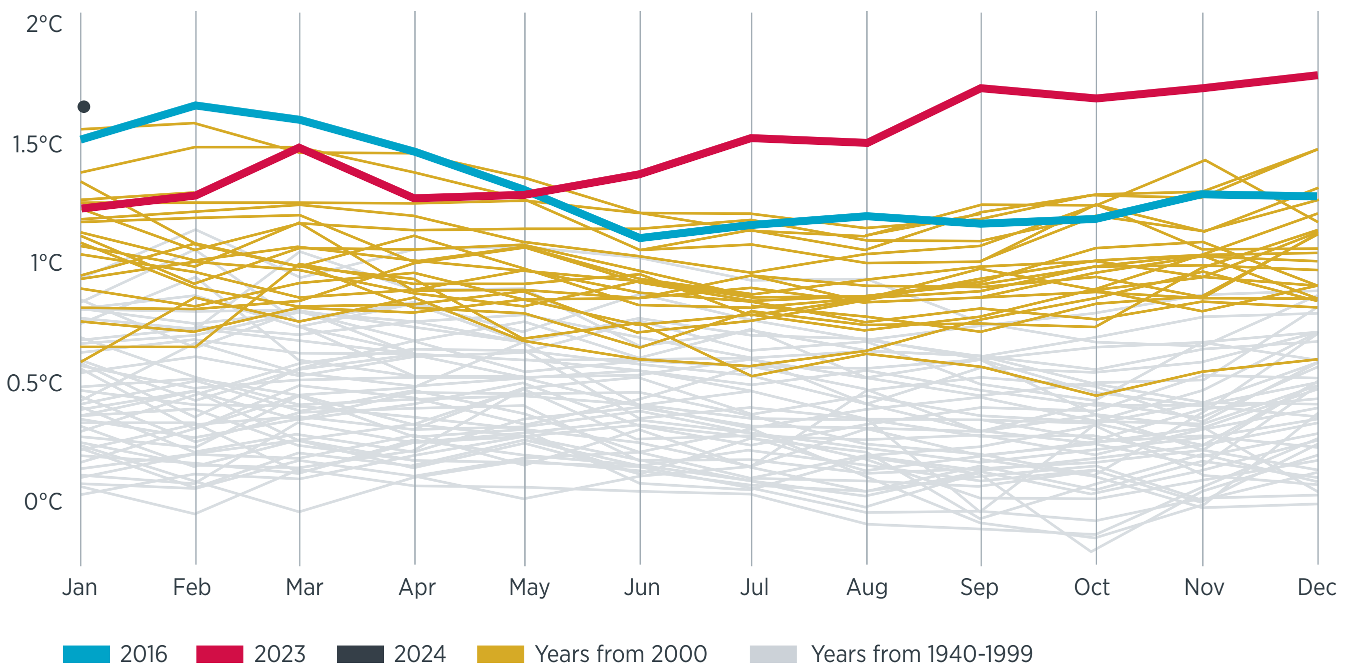
Source: ***Sandy Trust***

2.1 There is uncertainty about the future rate of global warming, and a concerning rise in temperature during 2023

The historic rate of global warming has been 0.18°C per decade from 1970 to 2010.[16] During 2023, the global average temperature rose at a faster rate than seen in previous years. This is documented in the annual State of the Climate report[17], and it is illustrated in the chart below of monthly average temperature anomalies compared with the pre-industrial era.

Figure 5: Global Surface Air Temperature Anomalies

Data ERA5 1940-2024, Reference period: 1850-1900, *Source: climate.copernicus.eu*



Source: IFoA analysis, Copernicus (Diagram was Inspired by the article "Climate records tumbled 'like dominoes' during world's hottest year" by Attracta Mooney, Steven Bernard and Kenza Bryan in the Financial Times, 9th January 2024)

The months since June 2023 were by far the warmest on record globally, by large margins. Several possible explanations for the 2023 temperature rise have been advanced, including the move into the El Nino period, a volcanic eruption that injected an unusually large amount of water vapour into the stratosphere, and a change in regulation of marine fuel oil in 2020 which reduced the amount of sulphate emitted by shipping, reducing the cooling effect of sulphate aerosols.[18]

A recently published paper focused on the September 2023 temperature anomaly, analysing temperature and climate model output to determine whether it could have been caused by internal variability of the climate, or requires another explanation.[19] The conclusion of the paper is that internal variability of the climate system, including El Nino, cannot explain the jump in temperature. This matters because we need to know how much of this temperature increase is temporary or permanent. If it is a temporary fluctuation, then we should expect temperature to fall again, in line with the long-term trend. On the other hand, it could be a permanent change representing a new baseline for warming. This would be more concerning, suggesting that climate model-predicted temperature rises may be understated. Any risk assessment of climate change should closely monitor this issue and make recommendations accordingly.

One area of uncertainty is in the magnitude of aerosol cooling[20] and therefore the effect of reducing marine fuel oil sulphur, which has a wide range of estimates. NASA has recently launched a satellite which will reduce this uncertainty: the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission.

2.2 Living in the tail - increased warming will drive more severe impacts across the planet

Climate change has arrived, with severe impacts emerging at lower temperatures than expected. The distribution has shifted. Arctic warming, sea-level rises and extreme weather events provide examples of climate impacts that are progressing faster than expected. Since 2020, we have witnessed record-breaking floods, fires, droughts, storms, temperature extremes and ice loss across the globe, impacting billions of people. As the 2023 State of the Climate Report states, *"we are entering uncharted territory."*[21] The Climate Crisis Advisory Group (CCAG) states: *"Ice sheet melt, rising sea levels, storm surges, typhoons, heat stress and other events pose real threats to lives and livelihoods, as demonstrated recently in Greece (wildfires), Libya (flooding) and the US (extreme heat). July and August 2023 were the hottest months ever recorded globally, while temperatures in September 2023 were the highest ever seen for that month. These and other extreme events will increase in frequency and magnitude as the planet warms further."*[22]

An area which has seen significant advances in scientific ability is attribution science, analysing how much more likely any event is as a result of climate change. Carbon Brief, a specialist climate science and policy think tank, has produced an interactive global map of attribution studies[23], a screenshot of which is shown in *Figure 6* below. Red indicates human influence has made the event more likely, more severe or both. Blue shows an event with no discernible human influence and grey an inconclusive study.

Figure 6: Global attribution map of extreme weather events to climate change.

Source: ***Carbon Brief Mapped: How climate change affects extreme weather around the world*** *(carbonbrief.org)*

> …the USA alone had experienced 23 events with losses exceeding $1 billion…

As well as the direct human societal impact in terms of lives, livelihoods and property lost or damaged, there is an economic cost to this. In 2023, by 11 September, the National Oceanic and Atmospheric Administration (NOAA) calculated the USA alone had experienced 23 events with losses exceeding $1 billion, well above the average since 1980 of eight events per year and the average for the last five years of 18 events per year. This included two flooding events, 18 severe storm events, one tropical cyclone event, one wildfire event, and one winter storm event.

Consultancy Verisk provides analysis on global insured and total economic losses. They estimate total economic losses now average $400 billion per annum, with a 5% chance of an annual insured loss of $200 billion or more in the next decade.[24] Verisk estimate total losses are 3 or 4 times insured losses, highlighting both a significant protection gap and the possibility of future total economic annual losses in excess of $1 trillion.

Lloyd's Futureset and the Cambridge Centre for Risk Studies go further in exploring a climate-driven food system shock as a result of extreme weather leading to economic losses of $5 trillion.[25] In this systemic risk analysis, they provide loss estimates for three scenarios ranging from major (1-in-50 year) to extreme (1-in-300 year). In the extreme scenario, they estimate the 5-year global economic loss to be $17.6 trillion.[26] Given the shifting distribution of climate change impacts, it is reasonable to ask for how long these probabilities remain appropriate, i.e. will the events they describe become more likely?

While it is uncertain exactly which events will occur in which locations, we can be confident of the trend over the rest of this decade. In 'No Time to Lose'[27], a collaborative paper between Exeter University and USS (a large British pension scheme), a physical climate narrative is presented that recognises the locked-in warming that we will experience till 2030, possibly accelerated as a result of El Nino. The paper presents a set of events covering heat extremes, droughts, floods and related societal impacts, such as food supply shocks and social stability. We explore societal impacts further in the next section.

2.3 Warming will continue until at least 2050 but there is huge uncertainty

To stabilise the climate, we need to not only reduce emissions but also remove GHGs at scale from the atmosphere. This means using technologies that do not yet exist and repairing the planet's natural carbon sinks. The levels of GHGs in the atmosphere mean we are therefore committed to further warming, but there is huge uncertainty around precisely how much further warming we will experience. This concept is referred to as 'committed warming'.

The principal causes of uncertainty are:

- Uncertainty around a key climate change assumption, Equilibrium Climate Sensitivity
- Uncertainty around future changes to natural and man-made factors impacting global warming

2.3.1 The sting in the tail of Equilibrium Climate Sensitivity

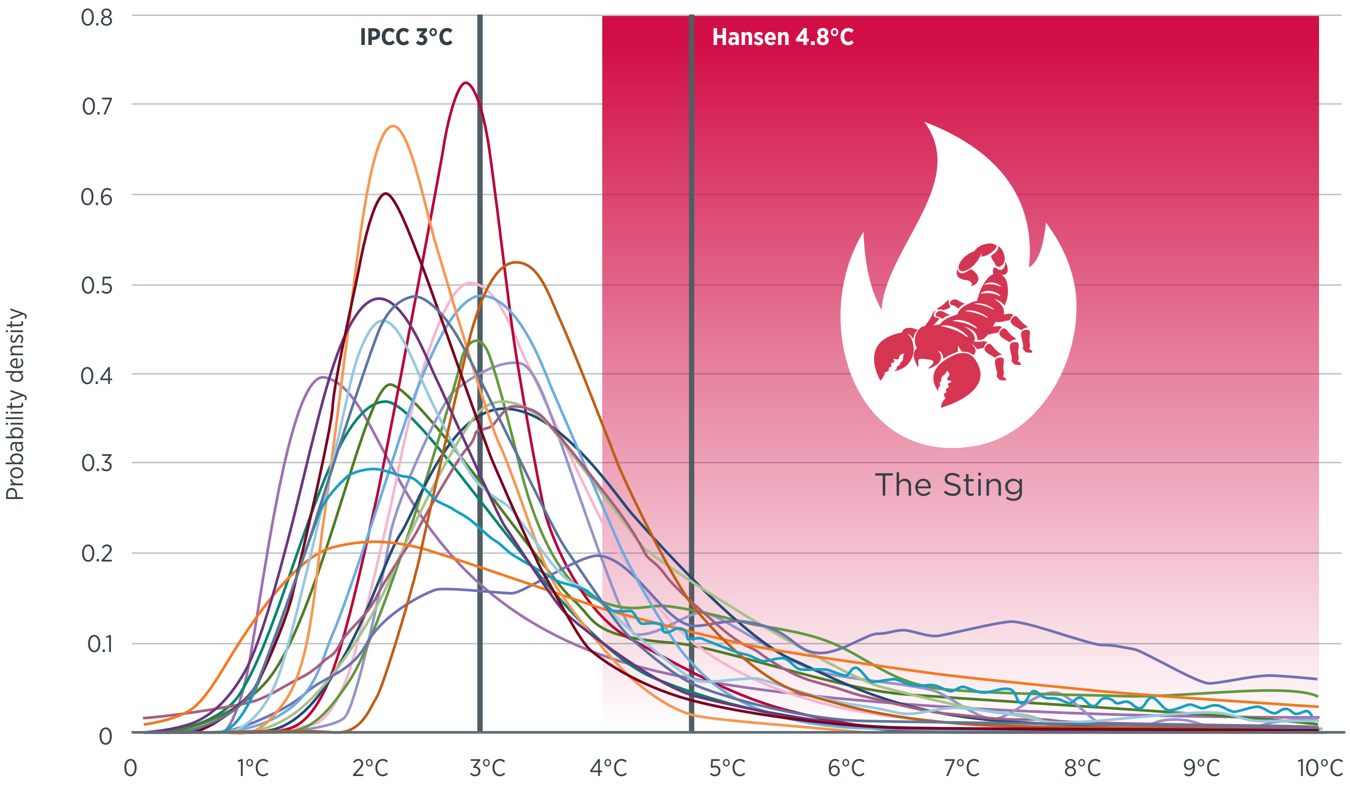
Equilibrium climate sensitivity (ECS) is the amount of warming we expect if GHG levels are doubled from pre-industrial levels. ECS was calculated in 1979 as being between 1.5°C and 4.5°C. These numbers have been remarkably stable over decades.[28] The Sixth Assessment report of the IPCC narrowed the range to the *likely* (66% to 100%) range of 2.5°C–4°C, with a best estimate of 3°C and a *very likely* (90% to 100%) range of 2.0°C–5°C. Some scientists estimate that the best estimate could be as high as 4.8°C, due to uncertainties associated with key variables, such as aerosol cooling and the rate at which ocean mixing occurs.[29]

An ECS of 3°C means that if we double GHGs, as we have effectively (technically radiative forcing has doubled)[30], then we would expect the planet to warm by 3°C. If the ECS is 4.8°C, then we would currently be on course for nearly 5°C of warming. This wouldn't happen overnight; in fact, there is uncertainty around how quickly the warming would happen as a higher ECS implies a longer response time. Given the uncertainty around this, this is another area where significant prudence is recommended from a risk management perspective.

However, ECS has a long tail to higher temperatures. This is due to uncertainties in the magnitude of feedbacks, such as cloud formation and break-up. Because of this uncertainty, estimates vary substantially.

A 2020 paper by Schlund et al[31] details ECS estimates from 31 models ranging from 1.83°C to 5.62°C. *Figure 7* below illustrates the challenge, showing the probability distributions for ECS from a range of climate models, to which best estimates have been added from the IPCC and an alternative estimate from a study led by the climate scientist James Hansen.[32]

Figure 7: Estimates of the Probability Distribution for Climate Sensitivity



Source: The Economics of the Climate,[33] IFoA Analysis

Focusing on the most likely outcomes under climate change lulls us into a false sense of security, since there is still an uncomfortably high probability of an ECS of 5°C or higher. As Kemp et al[34] point out, under the latest IPCC estimates there is an 18% chance of ECS being greater than 4.5°C. This equates to an almost 20% chance, which is a higher chance of failure than in the game of Russian Roulette.[35]

Climate policy should focus on the tails of the ECS distribution, rather than the central estimate. This is the lower probability, high impact tail risk event we seek to avoid.

2.3.2 The known unknowns - material sources of uncertainty and risk.

There are several potential factors which may act to further accelerate warming, including: carbon uptake by the oceans reaching a saturation point, the level of cooling from aerosols, tipping points, and cloud feedbacks.

- **Oceans** cover over 70% of the Earth's surface by area and account for over 95% of the biosphere by volume. Oceans have played a major part in mitigating global warming impacts to date, absorbing around 30% of carbon emissions.[36] It is not clear that the ocean will continue to absorb CO_2 at this rate on an ongoing basis. If the rate of CO_2 absorption were to reduce, this could materially impact the rate of global warming.

  Another source of uncertainty related to oceans is the patterning effect (essentially changes to the spatial pattern of sea surface temperature change)[37], which could act to increase committed warming.

  However, just as the ocean has played a major part in mitigating climate impacts to date, it could also play a major role in limiting global warming going forward. The ocean has significant potential to draw down carbon, both in flora such as mangroves, kelp forests and seagrass meadows, and in fauna through marine biomass generation. As with other untested methodologies, careful evidence-based research would be required before widescale deployment.

- **Nature** was recognized at COP28 with a first-of-its-kind joint statement on climate, nature and people.[38] While oceans may be the most material lever in nature with regards to climate change, terrestrial nature can also play a significant role in both mitigating climate change, as well as providing resilience to the impacts of climate change. For example, large tropical rainforests like the Amazon and the Congo draw down significant carbon but also play a major role in creating rainfall, both domestically and in neighbouring regions. However, the Amazon is also identified as a climate tipping point, which may lose its identity as a rainforest and tip from a carbon sink to a carbon source if deforested too extensively.

The Earth is a highly complex system and modelling its climate is an uncertain business.

- **Aerosol cooling** refers to the cooling effect of aerosols in our atmosphere that reflect solar energy. It is hard to be certain about how material aerosol cooling is, due to lack of historical measurement and interaction with clouds. Some scientists postulate that global warming historically (from increased GHG levels due to humans clearing and burning timber) was offset by aerosol cooling till the 1970s.[39] The IPCC in its AR6 Synthesis report estimates that aerosol cooling may offset about 10% of CO_2 warming[40], representing a reduction of global warming by as much as 0.5 degrees.[41] As we clean our atmosphere by moving to clean and renewable energy sources, we may lose the cooling effect of aerosols, further amplifying global warming. The aerosol lifetime is quite short, meaning that once atmospheric levels drop, the loss of their cooling effect may be immediate. Fuel standards introduced by the International Maritime Organisation to remove sulfur from shipping fuel have had the unintended consequence of carrying out an aerosol geoengineering experiment by removing this source of atmospheric aerosols, thereby accelerating global warming. A recent scientific analysis estimates this to be the equivalent of a sudden increase of atmospheric CO_2 from 420 ppm to 525 ppm[42] although there is not scientific consensus on this.
- **The impact of clouds** on global warming has been another area where it has been challenging to understand exactly what may happen as the planet warms, although several studies have shown that changes to cloud patterns could be significant and lead to increased climate sensitivity. Aerosols interact with clouds to decrease global warming and clouds themselves may act to reflect or capture heat, depending on their height. In summary though, the IPCC expect clouds to amplify global warming.[43]
- **Ice melts** and as it does, it absorbs significant energy that is required to melt it. However, the loss of ice also reduces Earth's albedo with dark ocean water absorbing much more energy than the ice it replaces. This is a factor in the accelerated warming of the Arctic and Antarctic compared to the rest of the world.
- **Tipping point impacts**, which we cover later in this section, may include significant release of greenhouse gases such as CO_2 (primarily) or methane from permafrost melt or reduction of CO_2 drawdown from Amazon dieback, which would act to accelerate climate change.

2.4 Carbon budgets, climate overshoot and scenarios failing the actuarial sniff test?

2.4.1 Carbon budgets are uncertain and the underpinning assumptions may not hold

The Earth is a highly complex system and modelling its climate is an uncertain business[44], as highlighted by the range of ECS estimates shown in *Figure 7*. One consequence of this is that carbon budgets are probabilistic. So a certain carbon budget will limit temperature to 1.5°C or 2°C with, for example, a 50% (half) or 66% (two-thirds) chance of that temperature not being exceeded. A 50% chance of success also means a 50% chance of failure. Likewise, a 66% or two-thirds chance of success means a third chance of failure, twice as high as the chances of losing Russian Roulette, a game few would choose to play, even for significant reward. We would be extremely unlikely to trust our pensions or savings to an insurer with a 50% chance of ruin, yet by basing our actions on these carbon budgets we are accepting this level of risk or failure, when it comes to climate change.

Underpinning carbon budgets are a set of assumptions that combine to make a climate scenario, a view of how the future will unfold that captures human elements as well as the natural world. Many scenarios that limit global warming to 1.5°C, or even 2°C, have a number of underpinning assumptions that might not hold, such as methane levels being reduced, deforestation ceasing, wide-scale implementation of carbon sequestration technologies, and no surprises such as tipping points. More realistic assumptions would act either to reduce carbon budgets or reduce the probability of success (keeping global temperatures below a certain level) for a set carbon budget.

It is unlikely that a regulated insurance company would be permitted to operate by utilising a set of assumptions that could not be validated, as this would increase the chance of it failing.

Indeed, as set out above, it now appears likely that there will be an overshoot of the 1.5°C temperature threshold. This means carbon budgets are likely to be smaller than those we are working with and will be negative for a temperature goal of 1.5°C, implying future removal of greenhouse gases from the atmosphere will be required.

2.4.2 Climate overshoot scenarios

The IPCC define a 1.5°C overshoot pathway as a *"pathway [that] sees warming exceed 1.5°C around mid-century, remain above 1.5°C for a maximum duration of a few decades, and return to below 1.5°C before* 2100"[45], as illustrated by the IPCC graphic from their 2018 Special Report on 1.5°C warming shown below.

Analysis of over 1,200 climate scenarios was carried out by a team at the Potsdam Institute for Climate Research to assess the feasibility of scenarios that limit global warming to 1.5°C by 2100, allowing for some overshoot.[46] Scenarios were grouped into two buckets:

- 'High overshoot scenarios' – where the Earth's temperature rises well above 1.5°C
- 'Low or no overshoot scenarios' – where the Earth's temperature is limited to close to 1.5°C

Low or no overshoot scenarios typically rely on countries going beyond net zero 2050 targets.

The research found that low or no overshoot scenarios typically relied on assumptions unsupported by current data, such as the ability to draw down over *"7 billion tons [of carbon] per year from the atmosphere by* 2050"[47], compared with a current global capacity of 43 million tons per year.

The stark conclusion from this work is that a high overshoot scenario is more likely than a low overshoot scenario, at this point in time. If the underpinning assumptions for high overshoot scenarios are required to be 'reasonable'[48], then only six of the original family of over 1,200 scenarios provide a credible pathway to limiting global warming to 1.5°C.

The lead author of the report, Lila Warszawski, is quoted as cautioning that: *"this research was conducted in 2019/20... we've had three more years where demonstrably the action required since the study was done to avoid an overshoot has not been taken...this shows us just how fleeting our chance to secure a safe climate future is."*[49]

All of which reinforces the need for broad and deep reductions in emissions, removal of greenhouse gases from the atmosphere and repair of broken parts of the climate system.

Figure 8: IPCC schematic of temperature pathways

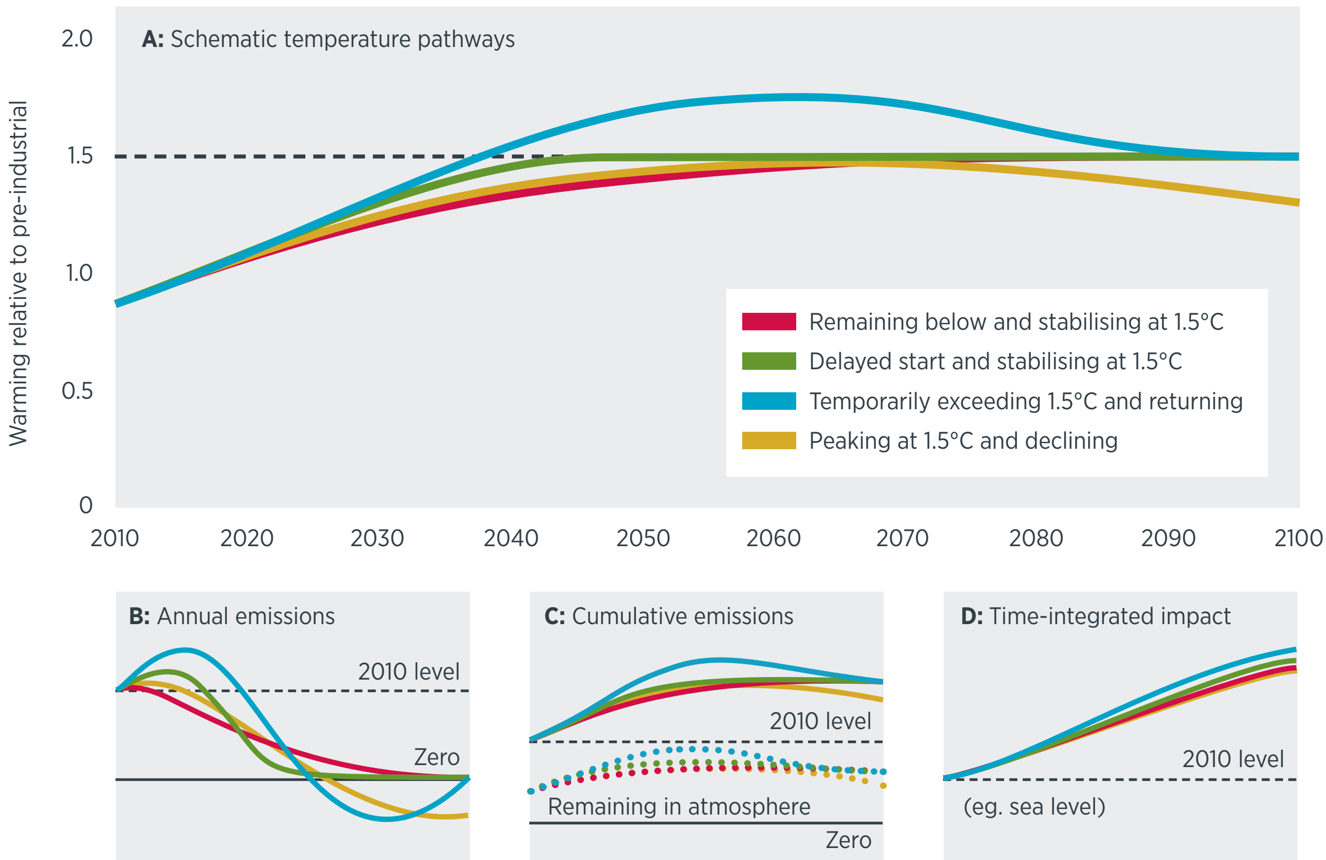


Figure 1.4 in Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu, and K. Zickfeld, 2018: Framing and Context. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 49-92, doi: 10.1017/9781009157940.003.

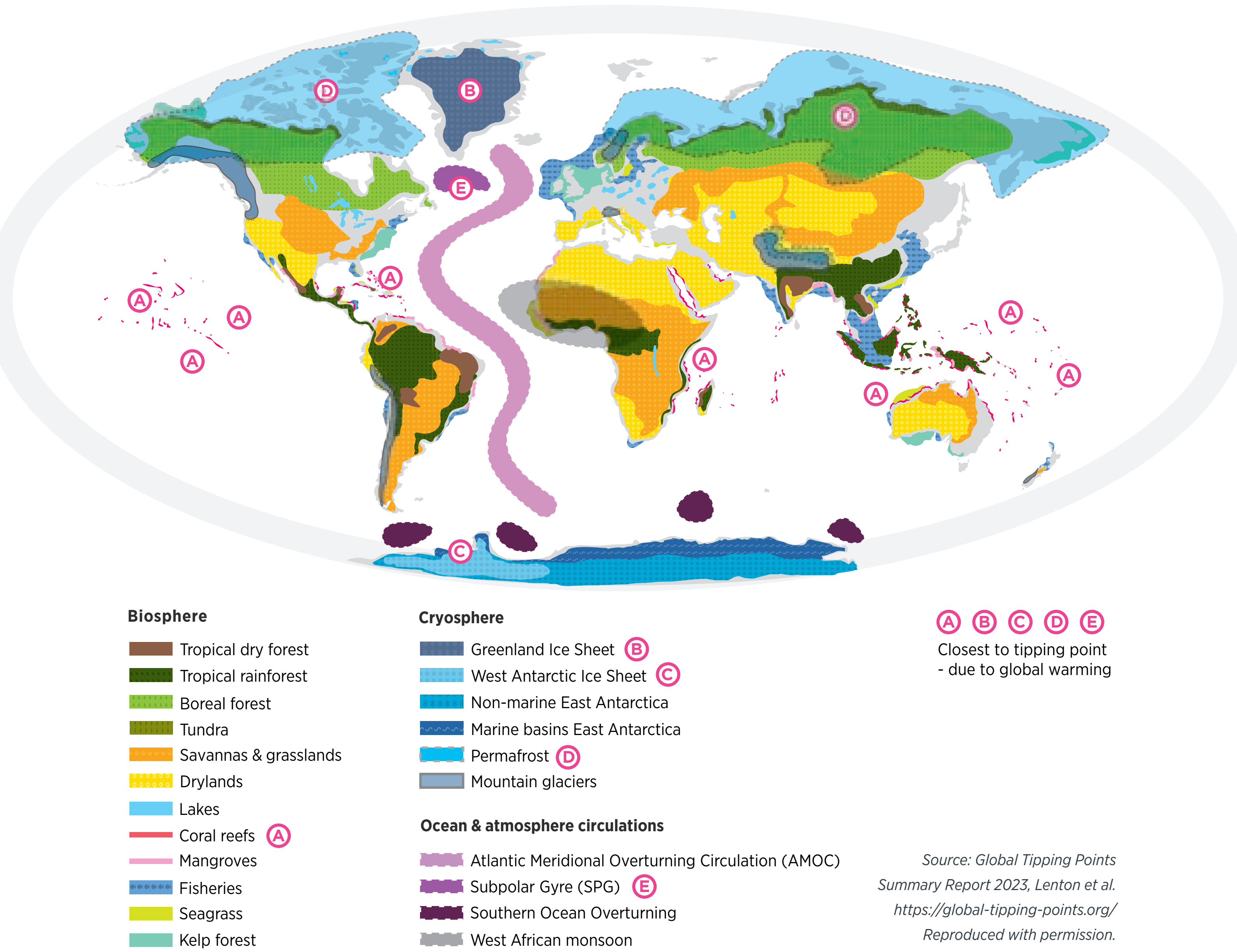
2.5 Tipping towards the point of no return

Recent research has shown that climate tipping points may be triggered at lower temperatures than previously estimated, with several at risk in the range of 1.5–2°C warming.[50] This strengthens the evidence for urgent action to mitigate climate change and limit warming to below 1.5°C.

Tipping points are thresholds at which abrupt and/or irreversible qualitative changes in parts of the climate system are triggered. Non-linear climate impacts may be driven by multiple climate change tipping points, which are not fully captured in IPCC estimates and are increasingly likely to be triggered as temperatures go past the 1.5°C level. These include the collapse of ice sheets in Greenland, West Antarctica and the Himalayas, permafrost melt, Amazon die back and the halting of major ocean current circulation.[51]

These tipping points may interact, triggering each other and cascading like dominoes. Once triggered, they may be irreversible and may act to accelerate global warming. This could be by a number of different effects, for example increasing GHGs, lowering albedo or redistributing heat in the ocean. This could increase the severity of impacts (e.g. accelerating multi-metre sea level rise). There are early indicators that we are now approaching some of these tipping points, as illustrated in *Figure 9* below, taken from the Global Tipping Points report published at COP28.[52] The report identifies five Earth systems already at risk of crossing tipping points at the current level of warming of 1.2°C: coral reef loss, the Greenland and West Antarctica ice sheet, Permafrost melt and the collapse of the sub-polar gyre.[53]

Figure 9: Parts of the Earth system identified in Global Tipping Points report



Source: Global Tipping Points Summary Report 2023, Lenton et al. https://global-tipping-points.org/ Reproduced with permission.

Tipping points are particularly important because, if triggered, we may find the climate moves into a different state that we no longer have the ability to impact by reducing our emissions.[54] This threat of negative impacts associated with abrupt and/or irreversible tipping point changes, and the potential for cascading effects, including amplification of global warming, make the prospect of breaching tipping points an existential risk.[55]

Although there is uncertainty around the precise temperature at which individual tipping points are triggered, scientists are making significant advances on estimating when they may be triggered, as well as developing diagnostic techniques for assessing how close tipping points are.[56] In addition to the five tipping points previously mentioned, another three tipping points are estimated to be at risk of tipping as we pass 1.5°C of warming: boreal forest, mangroves and seagrass meadows. The report estimates several more systems could tip if we pass 2°C of warming, including the Amazon rainforest and subglacial basins in East Antarctica.

The implications of tipping points include an impact on carbon budgets, which are likely to be smaller than those we are currently using for net zero, if we seek to avoid tipping points. Tipping points would also accelerate and/or worsen climate impacts, with these emerging at lower temperatures than previously thought. A simple thought experiment considers the impact of just two of these tipping points in combination: glacial melt in mountainous regions and ice sheet melt leading to faster-than-expected sea level rise. Around two billion people rely on meltwater from the third cryosphere, the Himalayan ice cap, for irrigation and drinking water. Hundreds of millions of these same people live in low-lying areas, such as Vietnam and Bangladesh, which may be inundated at high tide by 2050.[57] It is hard to see how a population could endure water shortages, flooding and the anticipated heat spikes; this is likely to be untenable and a forcing factor for involuntary mass migration, which may in turn drive other risks such as geo-political tension.

The latest science on tipping points[58] reinforces the need to race to zero and makes decarbonisation scenarios that feature temporary overshoot (i.e. allowing the temperature to increase beyond 1.5°C before reducing it again) significantly more risky. Tipping points should no longer be considered high-impact, low-likelihood tail risk events as they have historically been treated. They are now high impact, high uncertainty and increasingly likely events. We must take a precautionary approach to mitigate and plan for them.

> Only a low emissions scenario, which would require rapidly reaching net zero, avoids breaching the critical temperatures of most tipping points.

In *'Committed global warming risks triggering multiple climate tipping points'*, Abrams et al[59] explore the concept of committed warming and how likely we are to trigger tipping points. They find that even small increases in levels of atmospheric GHGs will lead to committed warming that is likely to lead to temperatures that cross the temperature thresholds of multiple Earth system tipping points. Only a low emissions scenario, which would require rapidly reaching net zero, avoids breaching the critical temperatures of most tipping points.

This is a difficult position, as there is a high chance of going through the 1.5°C barrier, perhaps as early as 2030 based on our earlier analysis. Depending on the rate of warming we experience post 2030, we may go through 2°C by 2050.

However, triggering multiple climate tipping points is incredibly risky, with the level of risk increasing with every fraction of a degree past 1.5°C. As Professor Johan Rockström said, when addressing the World Economic Forum at Davos in 2023, *"this shows scientifically that 1.5°C is a physical limit. It is not a political target…Four of these [tipping points] are showing scientific evidence of now being at risk already at 1.5°C…really putting humanity's future at risk. This is a planetary crisis."*[60]

3: Risky business – exploring the interconnectivity of risks

"Small changes can cause greater ones, unforeseen and perhaps already irreversible, due to factors of inertia. This would end up precipitating a cascade of events having a snowball effect."

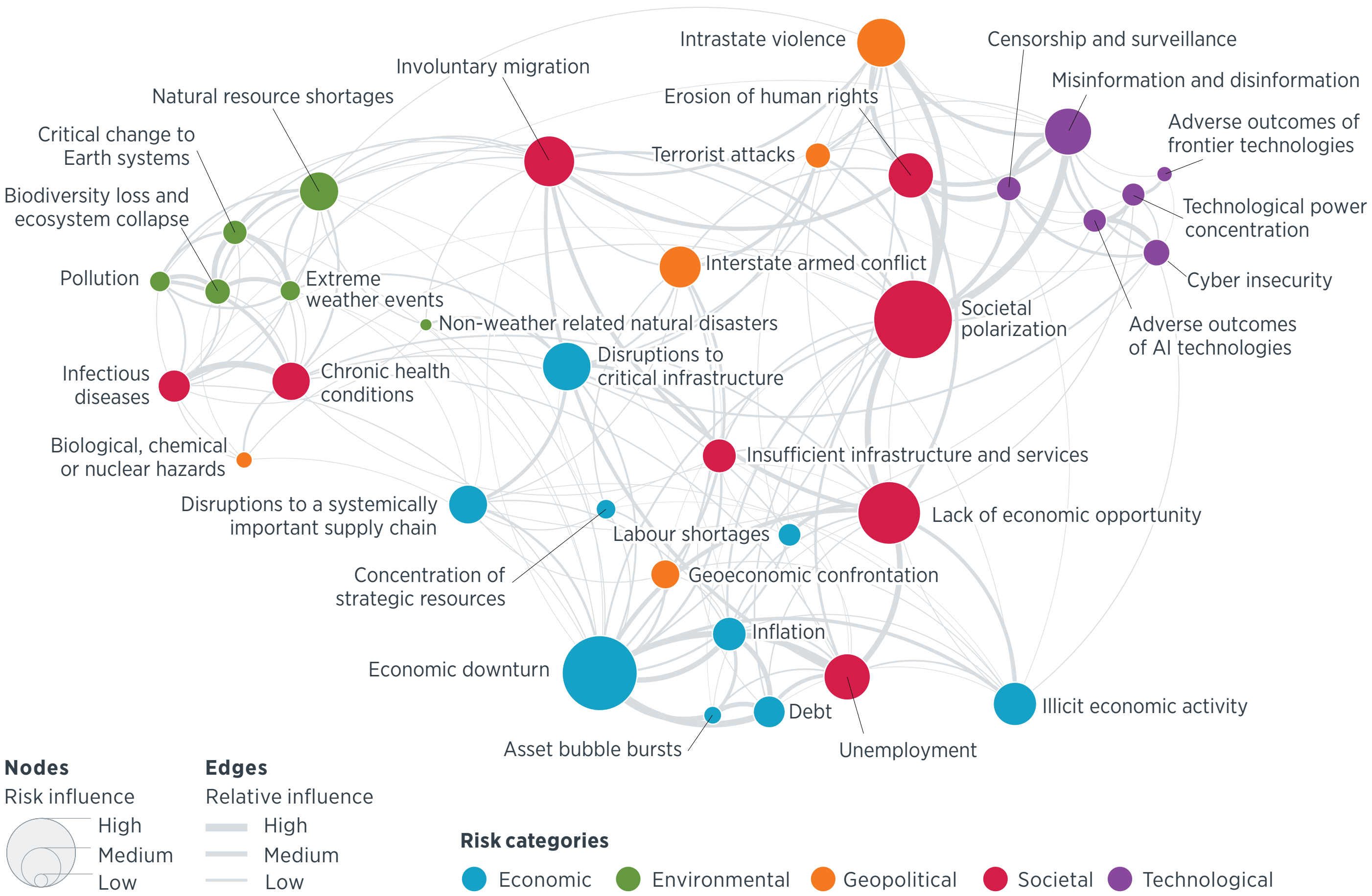
Pope Francis[61]

Climate change drives a complex basket of interconnected risks that could threaten the basis of our society and economy. Failure to consider these interconnections will underestimate risk.

The impact of a risk is a function of hazard (a process, phenomenon or human activity that may cause harm), exposure (the people, property or other assets located in a hazard-prone area) and vulnerability (the physical, social, economic and environmental factors that increase susceptibility to harm). Here we also consider an expansion of these factors[62], recognising that risks can also arise from responses to climate change. When hazards occur, exposure increases the potential for damage and vulnerability reduces coping capacity, together increasing overall impact. Responses can exacerbate or reduce overall impact or may even propagate new risks. Including a consideration of response encourages recognition of multi-sector impacts and allows a fuller consideration of trade-offs in decision making. In some cases, response may be the primary driver of outcomes.[63] It is the combination of risks that may be most serious and, while it is simpler to consider risks in isolation, it is clear that, in the real world, risks are interconnected.

The World Economic Forum (WEF) carries out an annual assessment of global risks and produces a risk interconnections map, shown below. WEF defines 'global risk' as the possibility of the occurrence of an event or condition which, if it occurs, would negatively impact a significant proportion of global GDP, population or natural resources. This demonstrates how a failure to mitigate climate change might drive resource crises, involuntary mass migration and ultimately state collapse, consistent with our analysis here.

Figure 10: Global risks landscape: an interconnections map



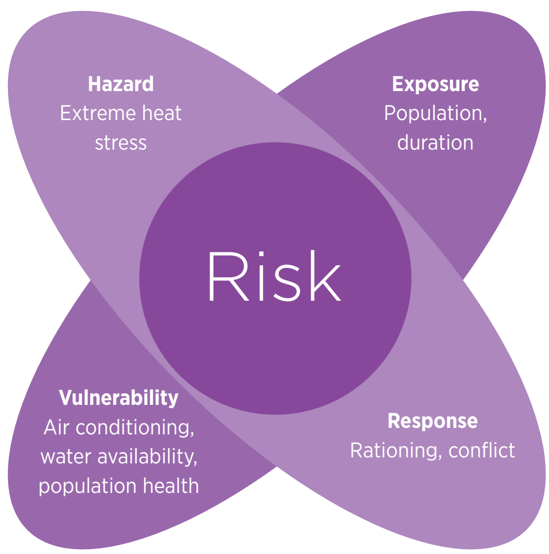
Source: World Economic Forum Global Risks Perception Survey 2023-2024

The concepts of exposure, vulnerability and response highlight the role that social factors such as economic, cultural and political conditions and values play in shaping the impact of these risks. Here, we use the term 'social fragility' to refer to factors that act to increase exposure and/or vulnerability.

For example, with temperature:

- Climate change will increase the hazard of extreme heat
- Exposure is the population impacted by extreme heat and the duration of the event(s)
- Vulnerability is linked to the ability of the population to withstand extreme heat which will include factors such as access to cooling, water and energy, as well as underlying population health
- Responses that influence overall impact include diversion of energy resources towards essential cooling services, restrictions on working hours or conflict due to scarce resources.

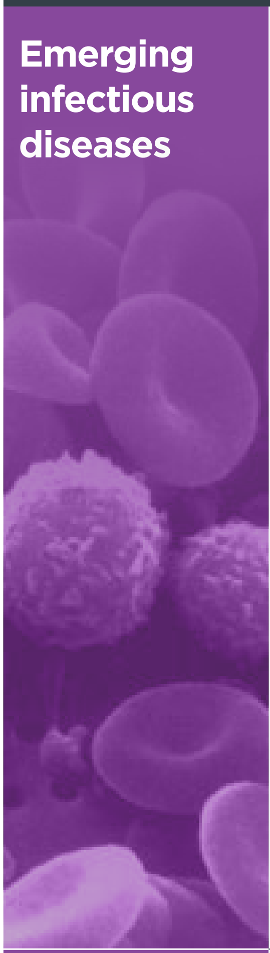
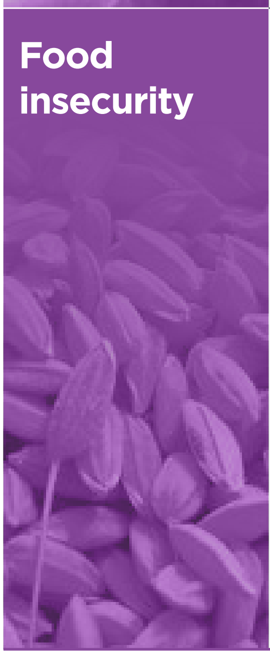
Figure 11: The hazard, exposure, vulnerability, response model for risk assessment.



Source: Lucy Saye

In this section, we explore how climate change is a driver for four systemic risks[64, 65]: extreme heat stress, food system security, water security and emerging infectious diseases. Climate change and biodiversity changes contribute to environmental breakdown[66] that increases the level of background hazard for all these risks, whilst social fragilities and responses propagate impacts across social and economic systems.

Table 1: Systemic risk assessment using the hazard, exposure, vulnerability, response model

Systemic risk	Societal fragilities increasing vulnerability and exposure	Responses that influence overall impact
Emerging infectious diseases 	• Infectious disease outbreaks increase pressure on healthcare infrastructure, especially those with little reserve capacity • Poor disease surveillance systems in areas at high risk of disease emergence negatively impact disease containment • Social inequalities and direct negative climate change impacts affect population health, increasing disease vulnerability • Food supply chains can be a source of disease outbreaks e.g. contamination of foodstuffs with mycotoxins, increase in bacterial pathogens • Population growth drives urban expansion and agricultural intensification, bringing people and domestic species into increasing contact with wildlife • Intensification of agriculture brings large numbers of genetically similar animals into close proximity (with poor husbandry compounding this issue) • Climate-change-driven increases in the geographical range of disease vectors and life cycles increase disease emergence • Global travel and transport facilitates rapid global spread of infectious disease	• Resilience in healthcare systems such as the ability to rapidly expand capacity, suitable personal protective equipment and trusted government advice on disease prevention can improve outcomes • Policies designed to limit disease spread may generate new economic risks such as reduced household incomes and financial bankruptcies • Ineffective global communication and coordinated action reduce ability to contain disease spread • Strained supply chains may drive protective polices by governments, further worsening supply chain issues
Food insecurity 	• Concentration of food production and global trade chokepoints and a lack of investment in chokepoint infrastructure reduces food system resilience • Concentration of fertiliser production and reliance of fertiliser production on natural gas exposes food production to gas price volatility • Population growth increases demand for food and in particular meat-based diets • Volatility of production inputs e.g. water stress • Food production shocks can lead to poverty, particularly for those on low incomes • Women are more vulnerable to food insecurity due to higher nutritional requirements, particularly during pregnancy. Inadequate diet increases pregnancy complications and infant deaths	• Disruption to domestic food supply increases the likelihood of reactive government policies, such as export bans that further undermine global food security • Responses that ramp up intensive agriculture as a short-term measure further worsen food production in the long term and undermine the climate and nature transition • Potential for mass migration, civil unrest and conflict driven by food insecurity

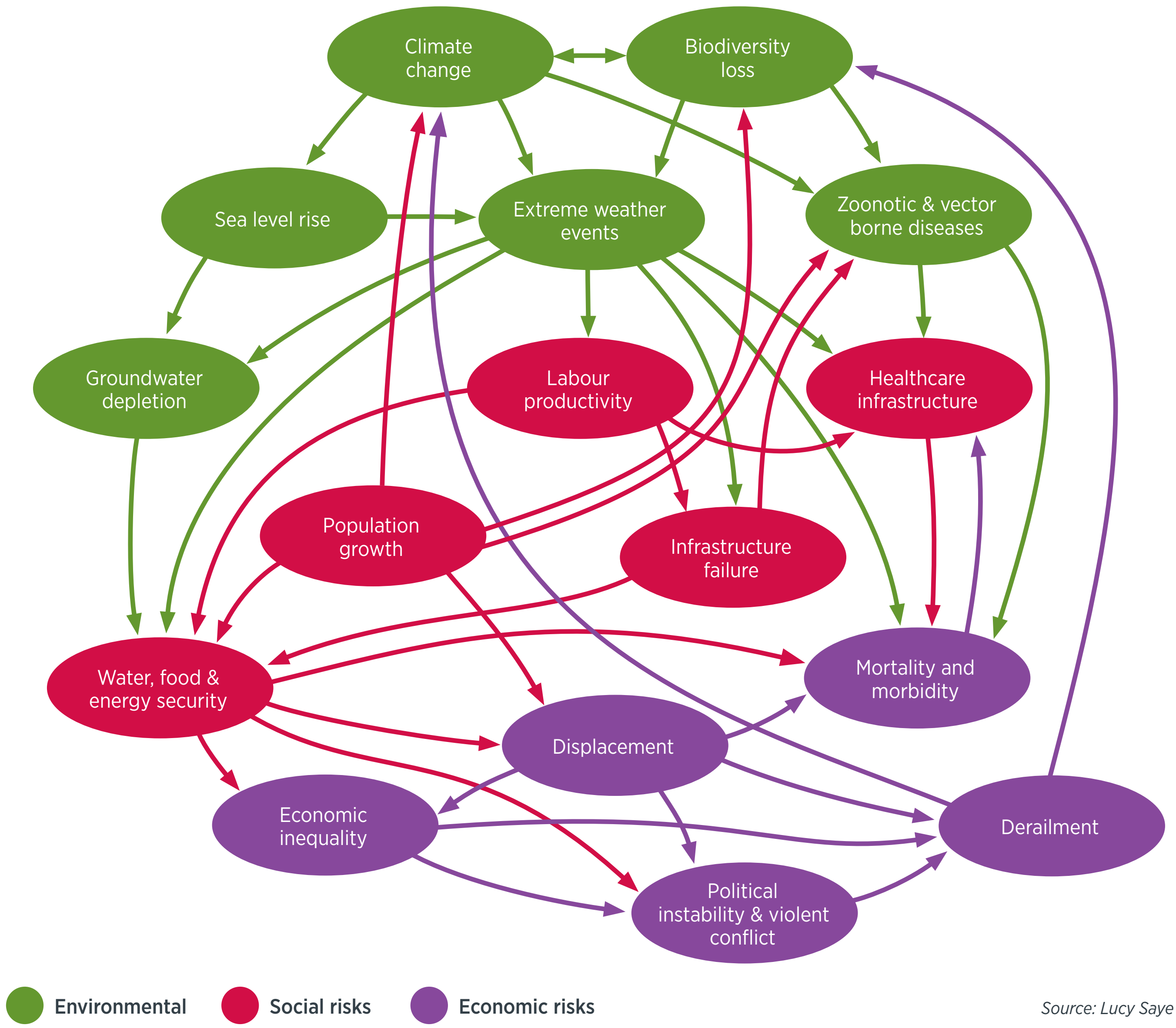
Systemic risk	Societal fragilities increasing vulnerability and exposure	Responses that influence overall impact
Water security 	• Population growth, production techniques and consumption of food increase demand for water • Agriculture and energy sectors are particularly vulnerable to water scarcity due to increased demand, e.g. impacts on crop yields could lead to food shortages. Trade-offs occur between food and energy security which depends on water for production and cooling • Lack of water impacts sanitation and hygiene, and can lead to a deterioration in health and wellbeing and strain on healthcare services • Long-term decrease in groundwater tables and soil moisture impacts agriculture and food production • Changes to rainfall patterns due to climate change and/or upstream activities like deforestation in neighbouring countries impact agriculture • Disruption to freshwater ecosystems and water transportation routes can affect commerce and international security	• Displacement due to water security could drive mass migration. This could in turn drive reactionary policies by governments and contribute to derailment • Competition for water resources increases conflict • Improvements to water management could reduce impacts of water scarcity
Extreme heat stress 	• Reduction in labour productivity in sectors such as construction and agriculture • Heat-related morbidity and mortality putting pressure on healthcare sector • Weakened physical infrastructure driving operational disruptions • Increase in vector-borne diseases • Interactions with food and water security, exacerbating resource shortages	• Forced displacement driving mass migration, civil unrest and conflict • Water or energy rationing may mitigate health risks but increases economic risks, civil unrest and political instability • Early warning systems, effective government messaging and rapid access to healthcare for vulnerable populations may reduce overall impacts

The list in the table above is not exhaustive, but we can use this as a basis to explore common drivers of these four risks, their interconnections, risk cascades that could emerge and the potential for passing risk tipping points[67], for example, running out of water. The combined impacts of these risks are widespread and severe, potentially including political instability, violent conflict and mass mortality. Collectively, these risk impacts may contribute to derailment risk[68], destabilising societies' ability to address the root causes, namely climate change and biodiversity loss.

The following causal loop diagram explores these risks, the common drivers that increase background hazard, their interactions and cascades, and the social systems that increase vulnerability and exposure to risk impacts.

> Displacement due to water security driving mass migration. This could in turn drive reactionary policies by governments and contribute to derailment

Figure 12: Climate change as a driver for interconnected risks, a causal loop diagram



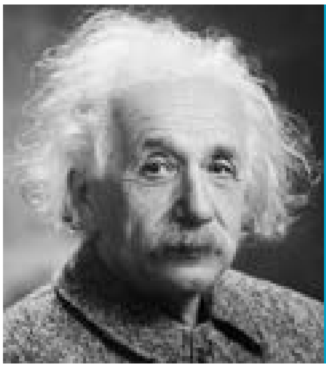
Source: Lucy Saye

Consequences of risk cascades

As shown in the causal loop diagram, these risks have common drivers and multiple points of interaction that could trigger or exacerbate each other. These risks all have direct effects on mortality and morbidity. They all cascade towards major systemic effects that feed into human suffering globally. Food, water and energy security can exacerbate economic inequality, fuelling involuntary migration, political unrest and violent conflict. Such crises are often assumed to focus political attention and public support to accelerate the sustainability transition. However, the risk of derailment has recently been documented. In this scenario, escalating demands to manage increasingly chaotic conditions could divert work, resources and political support from environmental action, worsening the changes.

The analysis presented here shows the importance of exploring interactions and common drivers between these risks. It also shows how responses may influence risk outcomes and generate new risks, since it is their combined impacts that may be most serious. Failure to consider these interconnections and responses leads to an underestimation of risk and an underappreciation of societal impacts.

4: Management actions for a stable climate



"We cannot solve our problems with the same thinking we used when we created them."

Albert Einstein

A Planetary Solvency risk assessment would likely lead to radically different climate policies. In this section, we present three recommendations for developing our approach.

These recommendations are:

- **I. Carry out a realistic risk assessment of climate change as a matter of urgency, and act on it**
- **II. Educate and take action to accelerate positive tipping points in the economic system**
- **III. Develop a Planetary Solvency framework to support human prosperity, now and in the future**

There are a number of implications for financial services firms, including a need to re-visit carbon budgets and related assumptions, a need to consider whether and how to move away from temperature commitments to focus on decarbonisation activity, ensuring their net zero approaches support real world decarbonisation, and how to constructively support policy action to accelerate positive tipping points.

I: Carry out a realistic risk assessment of climate change as a matter of urgency, and act on it

A full risk assessment of climate change should be carried out according to risk management best practice. This should take into account the full range of possible outcomes, including realistic worst-case scenarios, social and environmental tipping points, and the ways in which complex risks can compound.

Analysis in this report and previous reports shows that there is a need for better communication of key assumptions and judgements in climate change modelling and scenario analysis to mitigate model risk.

Alongside this, there should be more communication of what actuaries refer to as 'experience analysis'. Experience analysis refers to the ongoing review of key assumptions to derive any required changes, for example, review of mortality rates. While significant review of climate change experience takes place, e.g. in the State of the Climate reports[69], this is not necessarily communicated broadly, nor incorporated appropriately into implications for risk analysis and decarbonisation trajectories.

The status quo of poor understanding of model limitations and assumptions cannot continue.

Actuaries have well-developed standards for the development and governance of actuarial work, including risk models and the assumptions used in them.[70] The current way in which climate-change models and approaches are used would not consistently meet these standards. In particular, limitations and assumptions are not well understood and uncertainties are not communicated well. The consequences of this are serious, particularly when risks are mispresented or understated.

To mitigate this risk, we recommend the introduction of model validation and review of standards into climate change risk analysis and modelling approaches. The status quo of poor understanding of model limitations and assumptions cannot continue.

Realistic risk assessment would combine both qualitative and quantitative analyses, as outlined in *'The Emperor's New Climate Scenarios'*[71] and this report. The qualitative analysis would develop thinking on risk cascades and vulnerabilities. The quantitative analysis would work backwards from ruin, recognising that there are likely to be limits to our ability to adapt successfully to the disruption, that is likely to be experienced at higher levels of warming.

In *'The Emperor's New Climate Scenarios'*, we presented an approach to climate change risk assessment that leverages an established financial services risk management technique: reverse stress testing. In reverse stress testing, insurance companies ask themselves the question, "What would ruin us?" and work backwards from insolvency to construct a set of events that may lead to this. The idea is to engage management in thinking about combinations of risks, so they can build resilience into the business to withstand these.

The proposed approach does not explicitly model the impact of the various risks that may be faced; rather it takes the approach that we will be unable to adapt beyond a certain level of warming, recognising the challenges of accurately modelling the unknown impact of tipping points and other factors. This approach also provides an explicit link between an environmental factor (GHG levels) and current economic metrics (GDP). Adopting an insurance approach would then require us to reduce the probability of this outcome by reducing emissions more rapidly.

The red and orange lines in *Figure 13* show an approximation of GDP losses up to 100% at 4°C and 5°C of warming. This is a global average and different countries would be impacted at different rates. An alternative would be to calibrate to 90% or 80% GDP loss, assuming some adaptation that permits survival of a much reduced human population with associated residual economic activity. Three key assumptions are needed, which are:

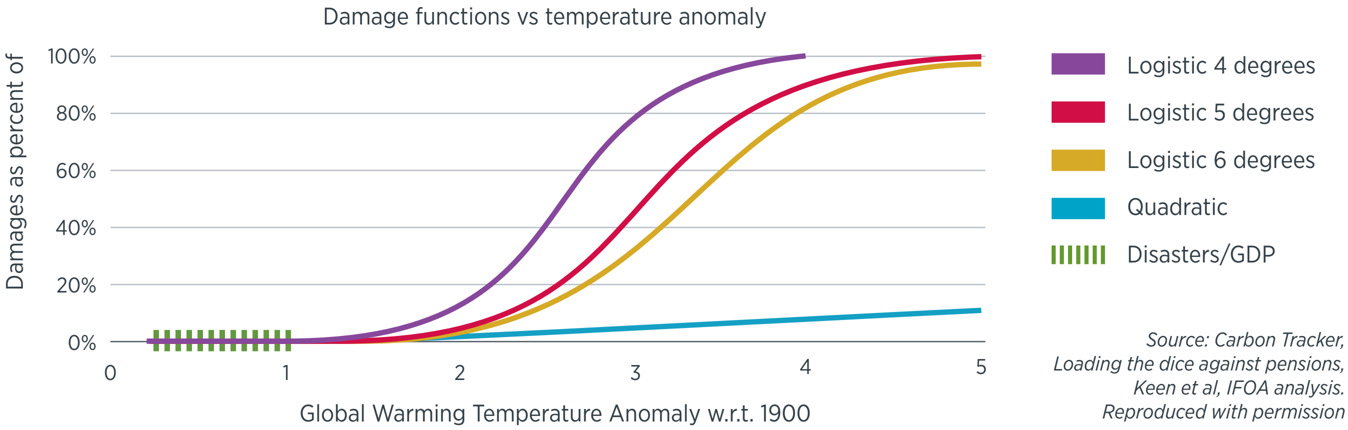
i. **How much warming do we expect for a certain level of GHGs?**

ii. **What will the rate of warming be?**

iii. **At what temperature do we cease to function as a society?**

Using a logistic loss function implies significant economic loss occurs at 2°C of warming. The rate of loss increases significantly between 2°C and 3°C, although there is significant variation depending on the assumptions used. With the 6°C ruin parameterisation, around 30% GDP loss occurs at 3°C of warming, compared with 80% GDP loss using the 4°C ruin parameterisation. Taking this approach would drive more realistic TCFD[72] results than the benign hot-house world disclosures we currently see. However, this is purely an illustrative example. What we need are damage curve estimates based on evidence-based thinking.

Figure 13: Climate damage functions - % GDP loss vs temperature



Source: Carbon Tracker, Loading the dice against pensions, Keen et al, IFOA analysis. Reproduced with permission

II: Educate and take action to accelerate positive tipping points in the economic system

As financial system professionals, actuaries are trained to work with both the asset and liability side of the balance sheet. Sometimes they will assess and model both together, an exercise referred to as Asset-Liability Modelling. It's useful to draw a parallel to this in the field of climate change, with climate risks being analogous to financial liabilities and the economy being analogous to financial assets. Both the climate and the economy are complex systems, therefore both can behave in a non-linear way.

Countries should invest in educating policymakers and others in realistic climate risk assessment and how to translate this into long-term policy, including accelerating positive tipping points.[73]

Positive tipping points have the potential to significantly accelerate the energy transition, which can be supercharged with the right policy support. The energy transition is exponential, global and this decade.[74] Capital flows into low carbon technologies are now over $1 trillion per annum, financing huge deployment of low carbon technologies with decreasing cost curves.[75] Some technologies are broadly on target with net zero carbon budgets, and there are significant policy commitments in a number of important markets, alongside focused sector-level collaborations to further drive progress.

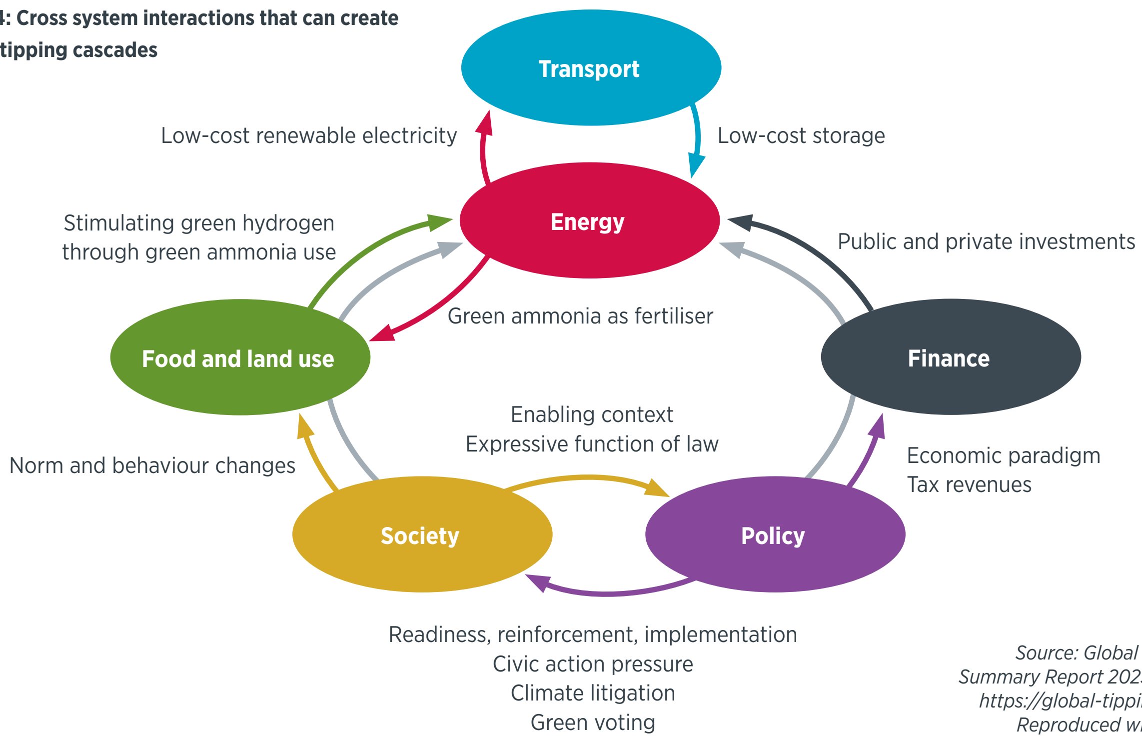
The energy transition in the power and light road transport sectors show all the hallmarks of the classic non-linear S curves of adoption that have been consistently observed with technology disruptions, from the adoption of cars in the early 20th century to the adoption of smartphones a century later.[76]

Even without taking into account the economic costs of failing to transition, a renewable energy economy is forecast to save trillions in operating costs when compared to our existing fossil fuel economy.[77]

An example of exponential growth is given in a recent article[78] by Nigel Topping, the UK Government's High Level Climate Champion for the COP26 UN climate negotiations, with reference to shipping: *"three years ago there was not one zero-carbon ship even being built anywhere in the world, then two years ago Maersk, the world's biggest container shipping company, ordered the first one. One year ago, there were 20 such ships on order. This year, Maersk's first zero-carbon ship is at sea and there are over 120 zero carbon ships on the order books i.e. 0, 1, 20, 120 - that's the nature of technology transitions."*

In *'Global Tipping Points',* Lenton et al describe the potential for this rapid transition as positive tipping points, explaining that *"positive tipping points offer the prospect that coordinated, strategic interventions can lead to disproportionately large and rapid beneficial results"* and that *"positive tipping points to accelerate social change are the only realistic systemic risk governance option"* to avoid triggering negative physical risk tipping points. Just as negative physical risk tipping points can interact with each others, so positive tipping points can create positive tipping cascades, where *"interactions across society, policy, technology and economy can amplify these cascades"*, as shown in the diagram below.

Figure 14: Cross system interactions that can create positive tipping cascades



Source: Global Tipping Points Summary Report 2023, Lenton et al. https://global-tipping-points.org/ Reproduced with permission.

The authors caution that *"Positive tipping points don't just happen, they need to be actively enabled. Most positive tipping points require interventions – technological innovation, political and social action, behaviour/norm change, and financial investment – that create the enabling conditions and alter the balance of feedback for tipping to occur."*

Put another way, further acceleration of the energy transition is not a given, despite the recent pledges at COP28 to treble renewable energy capacity by 2030. There are a number of challenges to overcome, including the upfront investment costs of the energy transition, investments in grid infrastructure which is already causing delays in connecting new renewable projects, the sheer quantity of new minerals required for the transition, uncertainty around political support, and ongoing disruption from fossil fuel actors who continue to plan for further expansion. There is also the risk of derailment; the distraction of dealing with increasing physical risks may simply prove too much for a concerted global effort on decarbonisation.[79]

III: Develop a Planetary Solvency framework to support human prosperity now and in the future

Climate change is intrinsically linked with other global risks that could impact our society, including nature and socio-political risks. While this report focuses on climate change, the risk cascades explored in Section 3 show that we need to approach risk management holistically and globally. We therefore recommend the development of a Planetary Solvency framework to inform the 2024 Biodiversity and Climate Change Conference of Parties.

Planetary Solvency would combine nature, climate and societal risk assessments, leveraging the planetary boundaries framework[80] to assess risks to ecosystem services, and thus to society and the economy. Planetary Solvency recognises that *"society needs to be viewed as part of the biosphere, not separate from it"*[81] and that *"our society runs on energy and materials"*[82] rather than labour and capital.

Planetary Solvency views nature as an asset[83] that provides ecosystem services, the 'liabilities' that our society and economy rely on nature providing. As with financial solvency assessments, Planetary Solvency would assess the ability of nature to continue providing the ecosystem services that underpin our society, both now and in the future.

Long term targets and management actions to manage risk

If solvency falls below targeted levels in financial services, management will agree a plan to rectify the situation, for example, companies agreeing to pay additional amounts into their corporate pension schemes to improve solvency positions. Insurance companies can bolster their reserves.

A Planetary Solvency objective might seek to minimise tipping point risks and other impacts to society. Some scientists have argued that, in the long term, we should not only seek to halt global warming but also reduce the global average temperature to within 1°C of the pre-industrial level.[84] Setting and agreeing such a goal could then be followed by development of a plan to achieve this.

Figure 15: Long term climate objectives

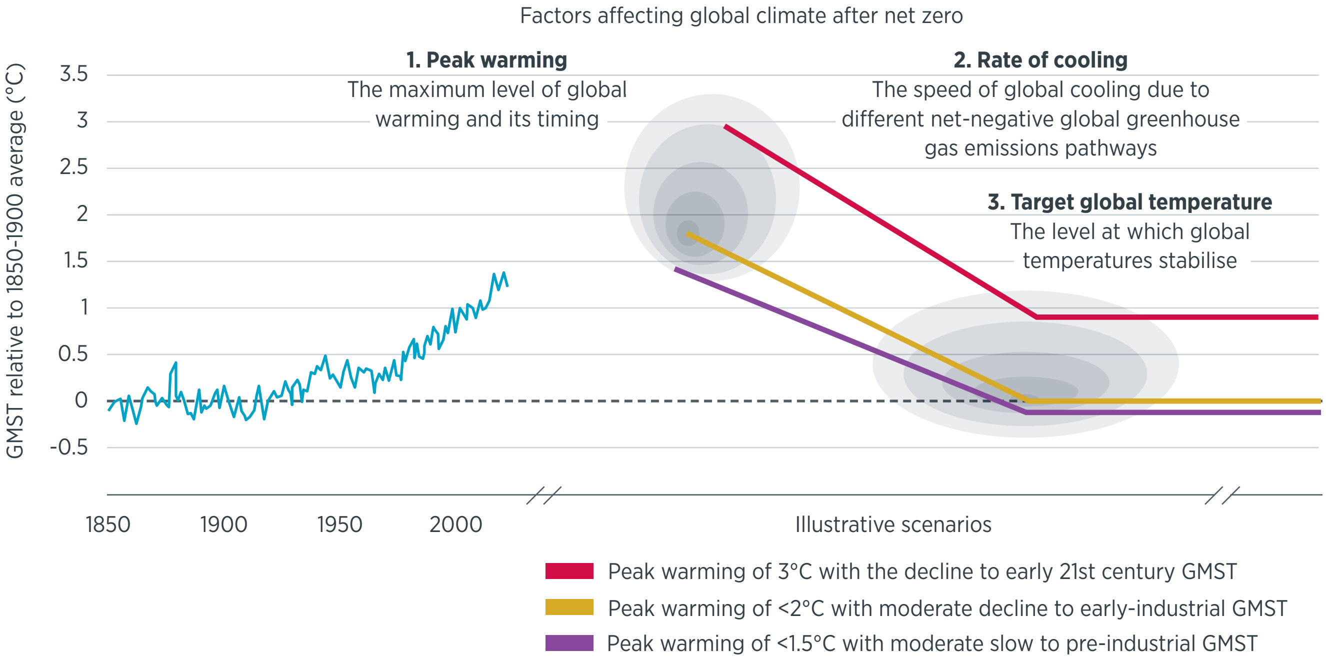


Diagram reproduced with permission from Preparing for a post-net-zero world | A D King et al (nature.com)[85]

A plan to reduce global temperature following peak warming would require the following components:

1. **Rapid reduction of emissions to zero**
2. **Removal of greenhouse gases from the atmosphere**
3. **Repair of damaged parts of our climate system**
4. **Building resilience of society to climate impacts through adaptation.**

If climate risk is sufficiently extreme, then emergency measures may need to be considered. These 'geoengineering' approaches include the rapid deployment of technologies which remove greenhouse gases and solar radiation management. Any choice to turn to such interventions needs to be careful, inclusive, and democratic. Democratic deliberation requires knowledge about these geoengineering measures, including the costs, benefits, and impacts. This will require sober, cautious discussions rather than avoidance. Geoengineering interventions pose risks and uncertainties of their own, and these need to be assessed and compared to the climate risk we are mitigating.

This report recommends that appropriate governance structures should be developed to oversee an urgent risk assessment of climate change, accelerate positive economic tipping points and embrace Planetary Solvency.

Future reports from the IFoA will further explore these ideas.

Implications for Financial Services Firms

1. This analysis shows that financial services' net zero budgets may not deliver a 1.5°C temperature goal, indicating a need to move away from temperature commitments (measurement) to focus on decarbonisation (activity), recognising the increased chance of overshoot.
2. To deliver this, financial services' net zero methodologies may move away from financed emissions to a more holistic approach focused on corporate activity, transition plans and engagement. A key principle will be to support real world rather than paper decarbonisation.
3. Financial services institutions should consider how they can constructively support accelerated long-term policy making to increase the pace of the energy transition. This so-called 'macro-stewardship' may become a more prominent feature of transition plans.

This report recommends that appropriate governance structures should be developed to oversee an urgent risk assessment of climate change, accelerate positive economic tipping points and embrace Planetary Solvency.

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