Institute and Faculty of Actuaries

University of Exeter

The Emperor's New Climate Scenarios

Limitations and assumptions of commonly used climate-change scenarios in financial services

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Contents

Nigel Topping
UN Climate Change High-Level Champion, COP26

Everyone who cares about the stability of our financial system should read this paper. Failing to include known non-linear effects in strategic thinking about climate change will lead to complacency, heightened risk and missed opportunities. So the scenarios that are used as part of TCFD processes really matter – both because economic damage will grow much faster and because the transition to clean technologies will happen much faster than conventional economic modelling suggests.

Mukami Njeru
Director, PWC

Unfortunately, achieving the net-zero transition is now an optimistic scenario rather than the best-estimate scenario. While this is not an ideal place to be in as a global society, it is a place from which we can make informed decisions on policies relating to managing climate-related risks. This paper shows there are fundamental gaps in our current approach to climate change analysis, highlighted by the application of actuarial principles. It is another example of how the actuarial profession can contribute to the management of climate risk. We trust it will be well received and, more than that, acted upon.

Lucy Saye
Chair, IFoA Sustainability Board

Climate and nature-related risks are subject to high levels of uncertainty, making scenario analysis a key tool in understanding and managing them. However, widely available climate change scenarios, while commendable, systematically underestimate the risks. Actuarial principles emphasise the need to understand and communicate material judgements and limitations to decision makers. This paper is a welcome addition, helping actuaries and other users of climate scenarios explore limitations and assumptions across the climate modelling chain, as well as setting out a way forward more aligned with climate science.

Julius Pursaill
Investment Adviser, Cushon

Few trustee boards have made significant changes to asset allocation as a result of scenario analysis, making it an expensive exercise of little practical value, with benign results potentially delaying decisions to support decarbonization. This situation needs to change; a radical new approach is needed to ensure scenarios add value, are actionable and more accurately represent the level of risk we face if we don't decarbonize.

Willemijn Slingenberg-Verdegaal
Managing Director Climate & ESG Solutions at Ortec Finance

It is critically important for stewards of capital to account for the state of the natural world, including climate change, when thinking through their investment strategies. A tick-the-box approach is no longer good enough. It is all about understanding and taking ownership of assumptions and modelling choices and acting upon insights to set appropriate investment strategies.

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

A decade ago, one of the world's top climate economists said it would be irresponsible to act as if dominant models of the economic costs of climate change were sensible. To continue to act that way now would be grossly negligent. This paper points the way to a more realistic assessment of risk, which is much needed.

Katie Blacklock
Non-executive director of Edmond de Rothschild, member of M&G's With Profits Advisory Board and Governor of the Health Foundation

This report is an important intervention that directly addresses and challenges the disconnect between what we know from climate science and what economic scenario analysis is telling us about the impact of doing nothing. Those in governance positions have a clear fiduciary duty to understand and mitigate the risks posed to clients' financial assets. To do so, we need to improve our collective climate literacy. Accepting the output of climate-scenario modelling at face value is at best inadequate and at worst dangerous – not just for the price of financial assets but for the planet. This report provides an excellent starting point for model users to understand the critical limitations and inherent uncertainties of scenario modeling when applied to an unprecedented and structural change in the risk landscape.

Dr Sarah Ivory
University of Edinburgh

There is a problem with the current climate-scenario modelling which means it does not accurately depict the future we know is coming, or the financial implications of this. Climate scenario users in financial services have two pathways forward. To spend all of your time understanding why existing models are wrong and tweaking them is equivalent to rearranging deck chairs on the Titanic. To build new models which get political buy-in on climate action is equivalent to launching the life boats. It still won't save all of us, but it's the best option we have.

Foreword

Professor Tim Lenton, Chair in Climate Change and Earth System Science at the University of Exeter

We have left it too late to tackle climate change incrementally. It now requires transformational change and a dramatic acceleration of progress.

A growing threat is the approach of ‘tipping points’ – thresholds which, once crossed, trigger irreversible changes, such as the loss of the Amazon rainforest or the West Antarctic ice sheet. Some tipping point thresholds have already been reached, while others are getting closer as global warming continues.

Once tipped into a new state, many of these systems will cause further warming – and may interact to form cascades that could threaten the existence of human civilisations.

However, some economists have predicted that damages from global warming will be as low as 2% of global economic production for a 3˚C rise in global average surface temperature. Such low estimates of economic damages – combined with assumptions that human economic productivity will be an order of magnitude higher than today – contrast strongly with predictions made by scientists of significantly reduced human habitability from climate change.

It is concerning to see these same economic models being used to underpin climate-change scenario analysis in financial services, leading to the publication of implausible results in the Task Force on Climate-related Financial Disclosures (TCFD) reporting that show benign, or even positive, economic outcomes in a hot-house world. This jars with climate science, which shows our economy may not exist at all if we do not mitigate climate change. It is essential that financial services institutions and regulators understand the limitations of these models and move towards realistic climate scenarios that recognise the catastrophic downside risk of a hot-house world.

My hope is that this will spur a further acceleration of activity towards net zero in financial services, as it is only by reducing emissions, repairing the climate system and removing greenhouses gases that we will avoid the worst impacts of climate change – and we will need the support of the capital and insurance markets to achieve this.

Actuaries have an important contribution to make here. The application of actuarial principles to climate-change scenario analysis demonstrates the significant weaknesses in current approaches. Actuaries also wield enormous influence in the global financial system. In addition to their role in the insurance markets, their work in pensions means they can impact capital allocation in long-term savings in a way few other professions can, – the financial system is critical to accelerating a range of positive socio-economic tipping points.

Because just as tipping points are part of the greatest threat we face, the same logic may also provide the solution. We have identified a variety of positive tipping points in human societies that can propel rapid decarbonisation, in areas including transportation, agriculture, ecosystem regeneration, politics and public opinion. This concept could unlock the stalemate – the sense that there’s nothing we can do about climate change.

Operationalising positive tipping points will require leadership across society to seek out and deliver these transformational opportunities. Like the negative tipping points in the Earth system, some positive tipping points are already in motion. We must now seize the opportunity to accelerate this process further.

Introduction

The IFoA Presidential Team

Matt Saker
President, Institute and Faculty of Actuaries

Louise Pryor
Immediate Past President

Kalpana Shah
President-elect

Following the policy briefing for COP27, *Climate Emergency – tipping the odds in our favour*, with Sir David King's Climate Crisis Advisory Group, we are delighted that the IFoA is continuing its collaboration with scientists on climate change with this paper in partnership with Exeter University's Global System's Institute. This paper focuses on how a deeper understanding of climate change, including tipping points, can improve financial services climate-scenario modelling.

Scenario modelling is an important component of the actuarial risk-management toolkit. Investigating adverse yet plausible scenarios enables actuaries to investigate how different combinations of risks could impact the future solvency of a financial entity and what action could be taken to mitigate this.

In the context of climate change, scenario modelling enables financial institutions and regulators to investigate the impact of different climate futures, which is important given the challenges we face. It has advanced considerably since its inception in financial services five years ago, and those who have advanced this should be congratulated on their significant efforts.

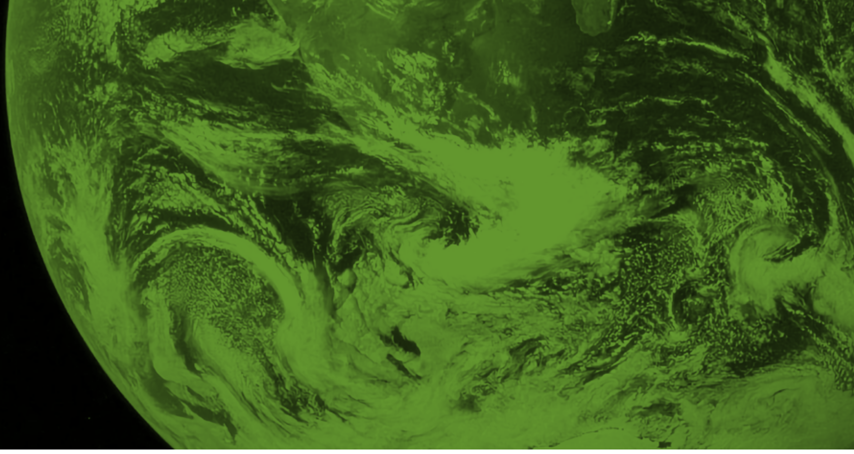
Climate-change scenario modelling is complex and nuanced, requiring sophisticated model builds that link different models together – physical climate models, economic models, insurance models and asset models. Many assumptions are required and, as with any model, it is a simplification of reality – model users must therefore understand the limitations and uncertainties. Indeed, communicating limitations, assumptions and uncertainties clearly to users is a key tenet of actuarial thinking, embodied in the Financial Reporting Council's 'reliability objective' for actuarial work that informs Technical Actuarial Standards:[1]

"To allow the intended user to place a high degree of reliance on actuarial information, practitioners must ensure the actuarial information, including the communication of any inherent uncertainty, is relevant, based on transparent and appropriate assumptions, complete and comprehensible."

This paper examines the limitations and assumptions in relation to climate-change scenario modelling practices in financial services, focusing on hot-house world scenarios of 3°C or more of warming. It demonstrates how current techniques exclude many of the most severe impacts we can expect from climate change, such as tipping points and second order impacts – they simply do not exist in the models. The consequence of this is that the results emerging from the models are far too benign, even implausible in some cases. It's as if we are modelling the scenario of the Titanic hitting an iceberg but excluding from the impacts the possibility that the ship could sink, with two thirds of the souls on board perishing.

This means the usefulness of the current scenarios is limited, as they do not communicate the level of risk adequately. More dangerously, the artificially benign results can easily serve as an excuse for delaying action, as consumers of these results, such as policymakers and business leaders, may reasonably believe the results to adequately capture the risks.

We hope this report will help by clearly highlighting areas of challenge, as well as providing ideas on ways to develop scenario techniques to better capture the severe risks we face. We also hope this more realistic assessment of risk will act to further catalyse the collaboration and investment into solutions that is required to ensure these risks don't materialise.



Key findings

Climate-scenario modelling is a structured exploration of different plausible futures.

It is a valuable tool for informing investment decision making, risk management and financial system resilience. It has evolved rapidly in financial services and is becoming mainstream. Regulators should take well-deserved credit for driving this adoption, along with the pioneering organisations and individuals who have led the way.

However, there are some important challenges that model users must be aware of, largely caused by the disconnect between climate scientists, economists and model users in financial services.

Challenges

Commonly used climate models in financial services are underestimating risk

1. **Many climate-scenario models in financial services are significantly underestimating climate risk**

   There is a disconnect between climate science and the economic models that underpin financial services climate-scenario modelling, where model parsimony has cost us real-world efficacy. Real-world impacts of climate change, such as the impact of tipping points (both positive and negative, transition and physical-risk related), sea-level rise and involuntary mass migration, are largely excluded from the damage functions of public reference climate-change economic models. Some models implausibly show the hot-house world to be economically positive, whereas others estimate a 65% GDP loss or a 50–60% downside to existing financial assets if climate change is not mitigated, stating these are likely to be conservative estimates.

2. **Carbon budgets may be smaller than anticipated and risks may develop more quickly**

   Earth-system models also have limitations and uncertainties with profound implications. We may have underestimated how quickly the Earth will warm for a given level of emissions, meaning we need to update our expectations as to how quickly risks will emerge. A faster warming planet will drive more severe, acute physical risks, bring forward chronic physical risks, and increase the likelihood of triggering multiple climate tipping points, which collectively act to further accelerate the rate of climate change and the physical risks faced. A significant consequence of this is that carbon budgets may be smaller than those we are working with and may now be negative for a temperature goal of 1.5°C. All of which reinforces the need to urgently reduce emissions, remove greenhouse gases from the atmosphere and repair broken parts of the climate system.

3. **Regulatory scenarios introduce consistency but also the risk of group think, with scenario analysis outcomes being taken too literally and out of context**

   Firms naturally begin with regulatory scenarios, but this may lead to herd mentality and ‘hiding behind’ Network for Greening the Financial System (NGFS) thinking, rather than developing an appropriate understanding of climate change. Key model limitations, judgements and choice of assumptions are not widely understood, as evidenced by current disclosures from financial institutions. Investors and regulators assessing financial resilience need to be particularly careful not to place undue reliance on artificially benign model results.

Moving forward

Education, qualitative scenarios and margins for uncertainty

1. **Education on the assumptions underpinning the models and their limitations**

   There is a discrepancy between climate scientists, those building the models, those working with the models, and decision makers in financial services. Deeper insights don't flow between the different actors, meaning that modelled results don't reflect climate science. Financial services institutions have expended considerable effort on producing results, meaning there has been less time for analysis and understanding. The limitations of the models and uncertainty in results is communicated badly or not at all. All those involved in climate-scenario modelling – including model providers, professional advisers, those in governance positions and regulators – need to develop an appropriate understanding and work to break down silos.

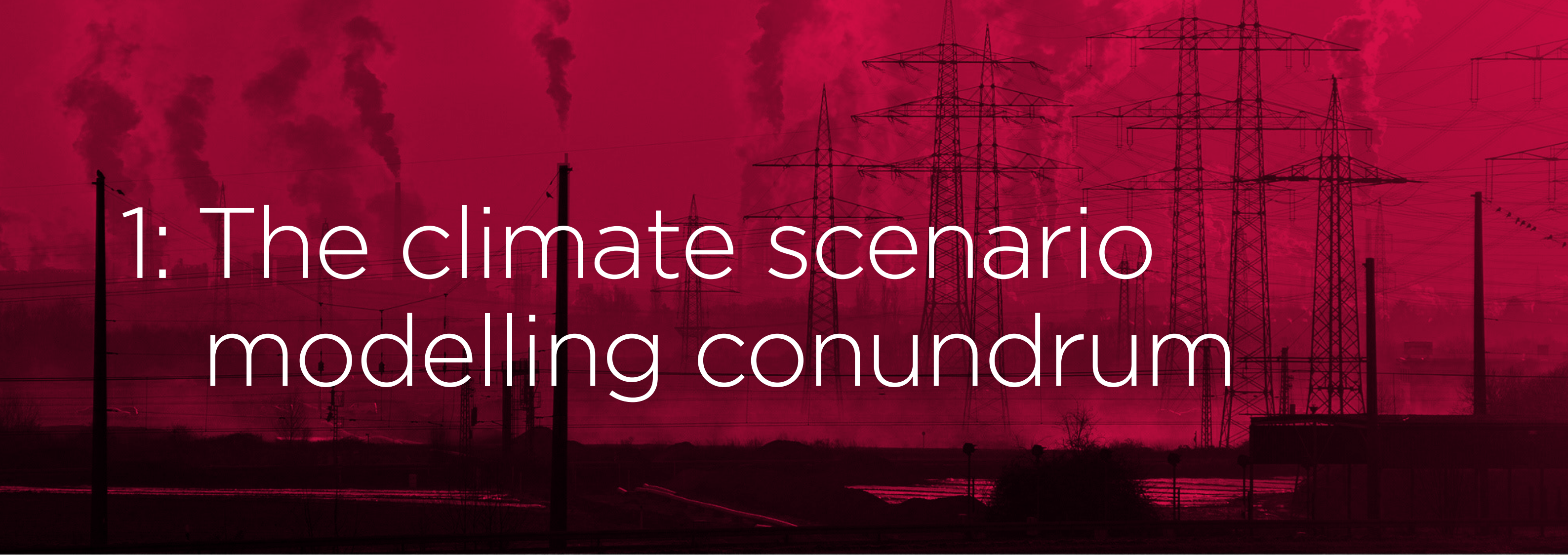
2. **Development of realistic qualitative and quantitative climate scenarios is required**

   Financial institutions should be encouraged to develop plausible qualitative and quantitative scenarios alongside regulatory ones. A simple quantitative approach could be to use a reverse stress-testing approach based on a ruin scenario of 100% loss of GDP at a certain temperature limit. This should be supported by robust internal debate around assumptions, development of appropriate investment beliefs around climate-related risks, and opportunities to foster ownership of assumptions and mitigate risk of group think. This should include developing thinking on ways in which climate change may realistically evolve based on current emissions and warmings.

Time is too short to wait for models that are perfect.

3. **Model development required to better capture risk drivers, uncertainties and impacts**

   Time is too short to wait for models that are perfect. Development is needed, including looking beyond the commonly used general equilibrium economic models that underpin many approaches today, to find solutions that can realistically capture risk drivers and the interaction between policy, technology, the real economy and markets. A practical fix is to use qualitative scenarios that reflect the emerging reality of climate change to complement models, as well as out-of-model adjustments and margins to reflect uncertainty.



1: The climate scenario modelling conundrum

Modelling global warming, and our society's reaction to it, to assess physical and transition risks under a range of possible future scenarios is hugely complex.

For each scenario we wish to assess, we need to estimate the level of future greenhouse gas (GHG) emissions driven by how quickly we transition, how quickly the planet will warm due to these emissions, what impacts our global society will feel and, finally, what this will all mean in terms of economic outcomes. The complexity is compounded by the limited relevant historical data on which to base our modelling – our society has not been through an energy transition of this pace and scale while simultaneously facing into physical climate change. It is a challenge that is matched in its complexity only by its importance.

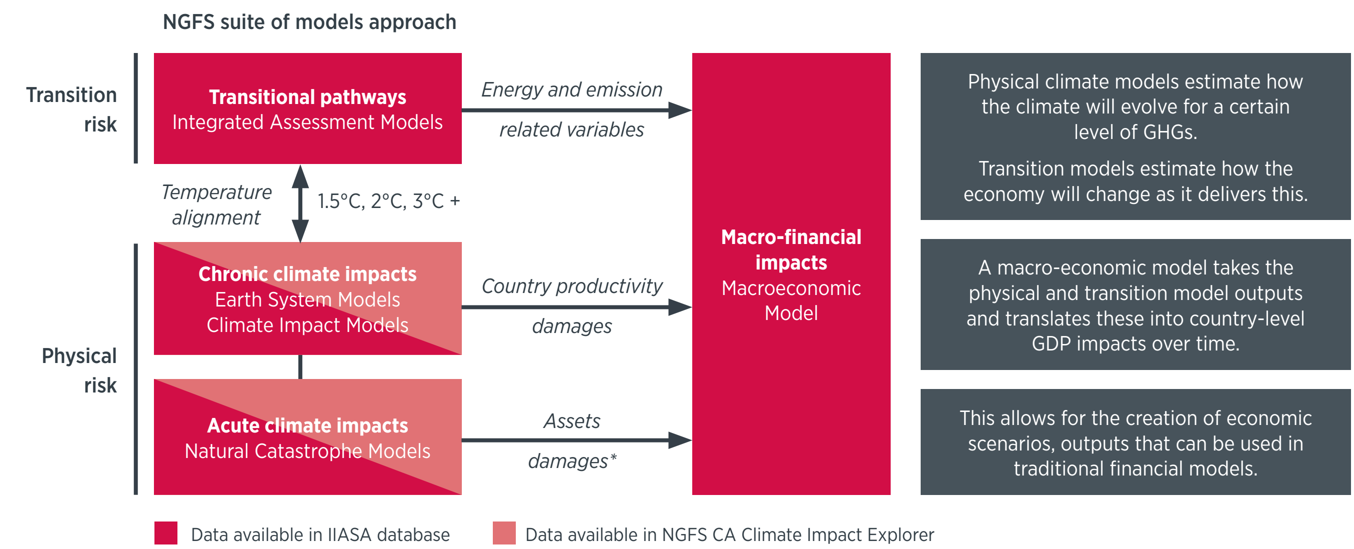
Further risk, uncertainty and complexity is introduced by matters such as the inherent uncertainty in climate science and the pace of climate change (faster than expected) driving extreme weather events and the emergence of climate tipping points. These reinforce the importance of limiting global warming to 1.5°C, with warming beyond this level extremely risky, with an unknown set of impacts. It is overwhelmingly in our economic interest to limit global warming.

However, this is not reflected in modelling results, which show a wide range of economic impacts from a hot-house world scenario where we fail to transition. Some models estimate this to be economically positive, which is implausible given the significant devastation and risks we expect to face.

Climate-change scenario modelling – setting the scene

Modelling how an individual financial organisation such as a pension scheme, insurance company, bank or investment firm might be impacted by physical and transition risks in a range of climate scenarios is complex. *Figure 1* below illustrates at a high level the different models that are required, with further details provided in **Appendix B** on the scenario creation process. Users in financial services may only be familiar with the models used in the final state of the process.

Figure 1: Schematic of climate-change scenario modelling



Source: NGFS, 'NGFS Scenarios for central banks and supervisors, September 2022', reproduced with permission

The climate-modelling conundrum – limited relevant data, high uncertainty and interconnectedness

Modelling climate change and society's reaction to it is hugely complex, requiring us to make assumptions about many unknown factors for each scenario we wish to model, including:

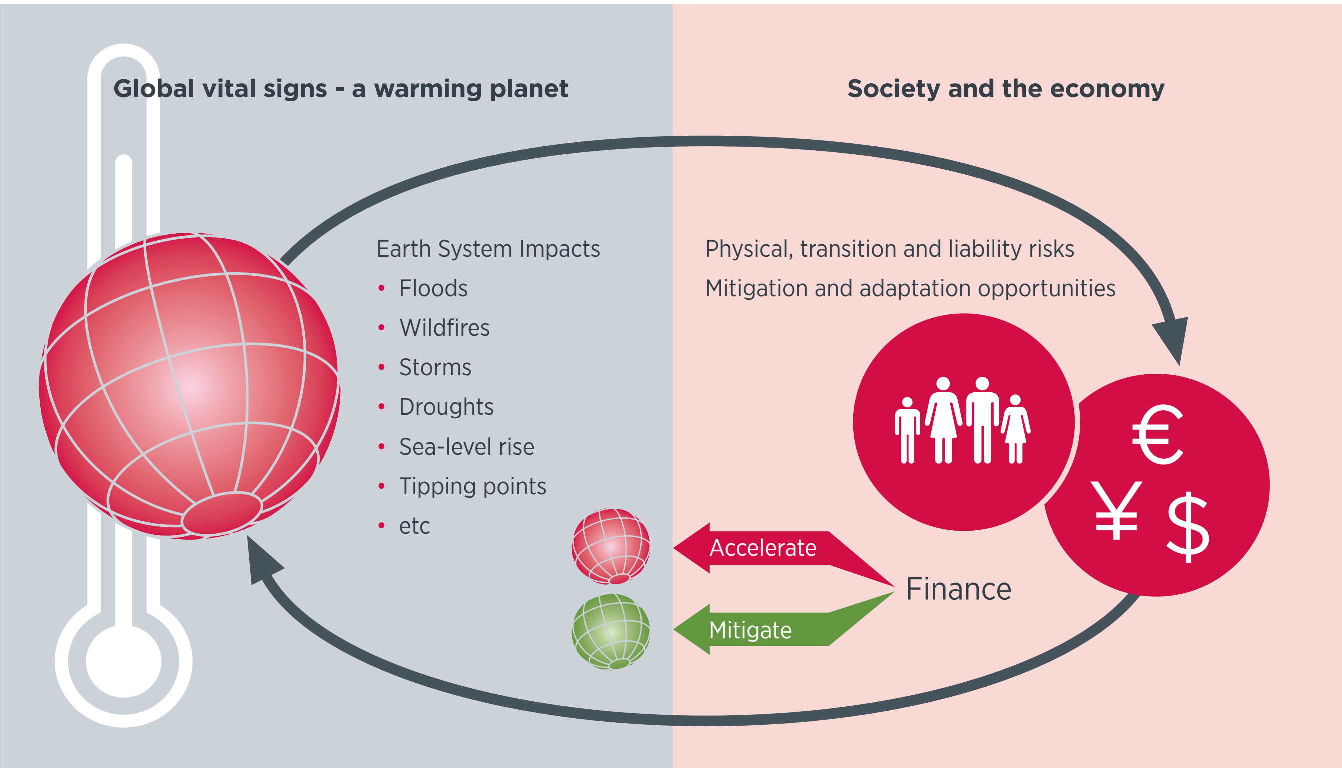
- The level of future emissions in each scenario
- How quickly the climate will warm for a given level of emissions
- Whether we cross climate or ecosystem tipping points
- The level of damages we will experience as the climate warms, mitigated by adaptation
- How quickly we will transition as we react to the physical changes we experience
- The pace and scale of the transition in different geographies, economies and sectors
- How to incorporate factors such as land use, technological change and nature.

Actuaries typically set assumptions in a model using past data. For example, examination of mortality rates enable actuaries to set assumptions for life insurance or pensions. Historic stock market returns allow actuaries to estimate what sort of economic volatility might be experienced in the future. If things change, such as mortality improvements, then actuaries adjust their assumptions accordingly.

With climate modelling there is limited relevant past data. There is no historical precedent for the rate of increase of GHGs, so we cannot be confident about how quickly the planet will warm, although we can estimate where we might end up with this level of GHGs. Similarly, our economy has never been subject to an energy transition of this speed and scale, alongside the increasing physical risk environment we face into. Modelling physical and transition risks based on past data is akin to looking backwards from the deck of the Titanic on the evening of 14 April 1912 and predicting a smooth passage to New York because no icebergs have yet been hit.

Further complexity is introduced because many of these factors are interdependent. For example, a rising physical risk environment may bring increased support for policy shifts, which will accelerate the transition, arguably a phenomenon we are now observing. Ongoing investments into fossil fuel infrastructure will bring increased emissions, which will accelerate warming, another current phenomenon. *Figure 2* below illustrates this interaction between the Earth's physical climate system and our human society.

Figure 2: Double materiality – the interaction between the physical climate and our economy



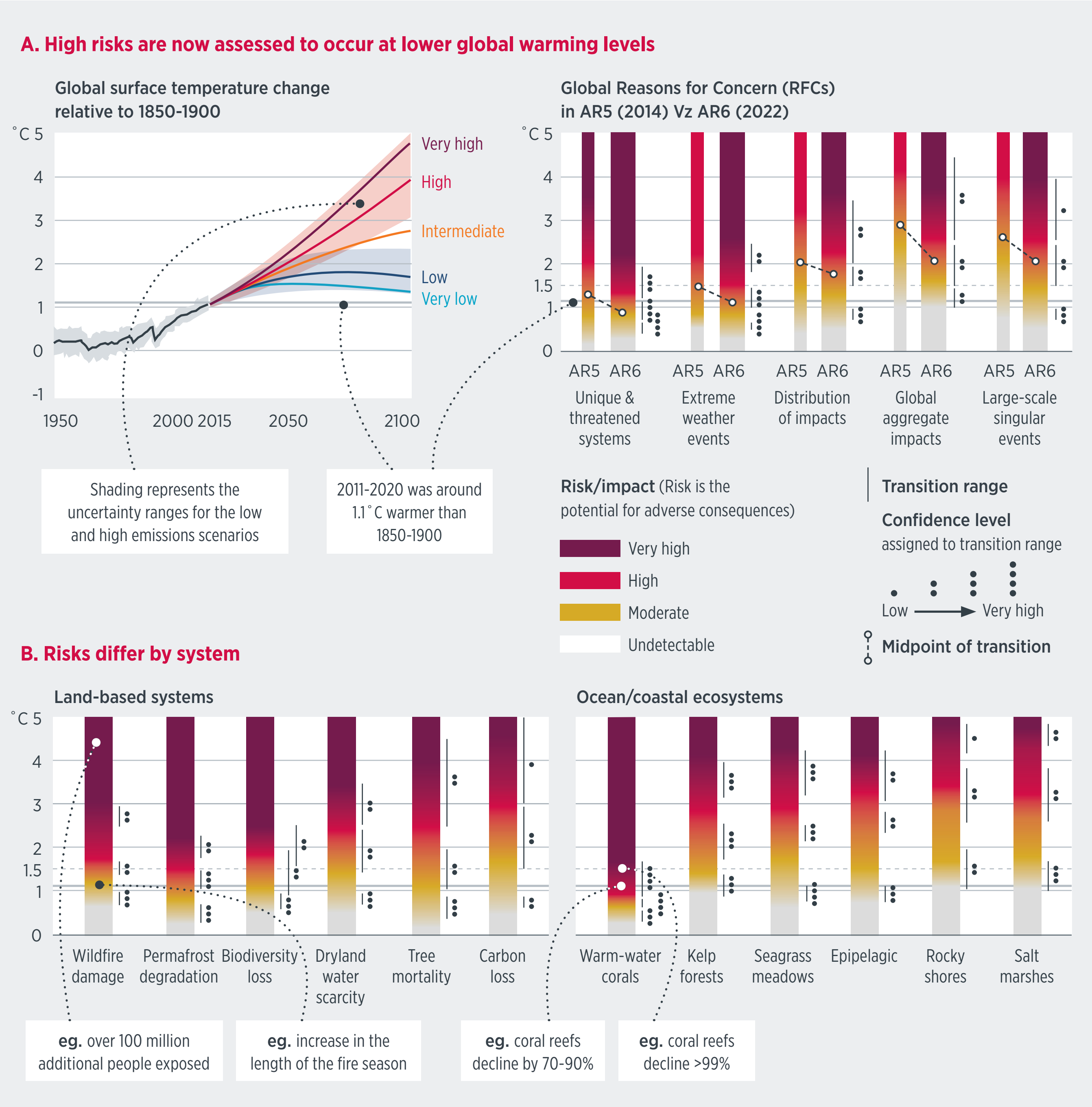
Source: Sandy Trust, reproduced with permission

The Paris Agreement recognised that financial institutions have a critical role to play in climate change, with the inclusion of a goal to make finance flows consistent with a pathway towards low GHG emissions and climate-resilient development, resulting in the creation of the Glasgow Financial Alliance for Net Zero (GFANZ)[2] to help enable this. While GHG emissions physically drive global temperatures, financial systems play a huge role behind the scenes because every pound that is lent, spent or invested has a real-world impact (so arguably could be viewed as a risk transfer payment). Therefore, climate change is a dynamic problem, where the financial system is not only impacted *by* climate change but also *impacts* climate change, a concept known as double materiality.

Climate change – a risky and uncertain business, tipping into the unknown

Climate change is happening more quickly than anticipated, with severe impacts already being felt by millions globally at the current level of warming of 1.2˚C. A consistent pattern of corrections over time is observed, in the direction of worse than we anticipated, leading to downward revisions of 'safe' temperature levels towards 1.5˚C as illustrated in *Figure 3* below, a limit we are fast approaching. These impacts are expected to increase as the temperature rises further. *Figure 3* also shows how uncertain climate change is, with the range of uncertainty on the temperature for high and low-emissions scenarios overlapping until around 2070.

Figure 3: Risks are increasing with every increment of warming



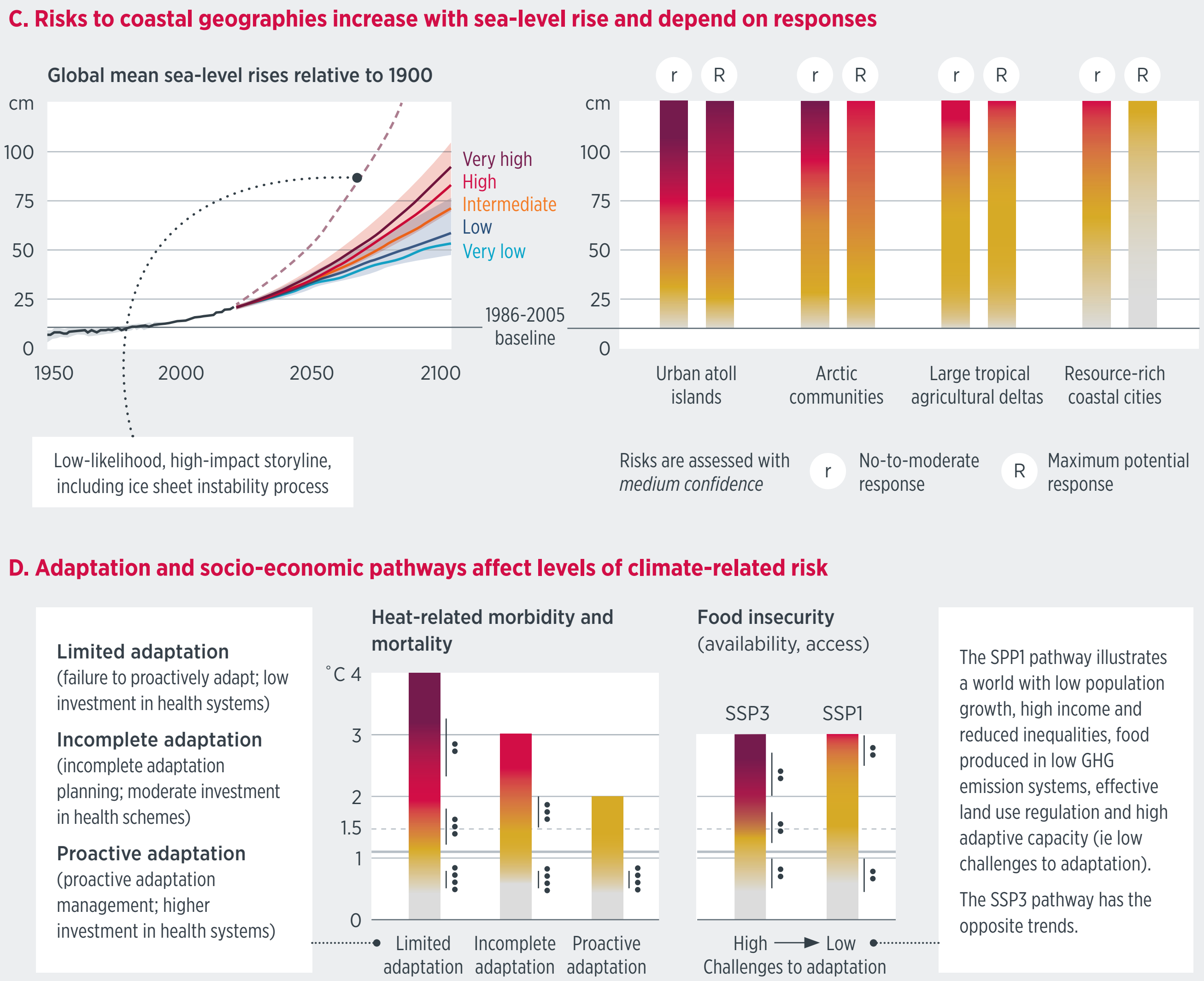


Figure SPM.4 from IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, (in press). Report. © IPCC, reproduced with permission (**Figures: AR6 Synthesis Report (ipcc.ch)**)

One of the drivers for the range of uncertainty around temperature outcomes for different emissions scenarios is the uncertainty, and hence probabilistic nature, of carbon budgets. As detailed in the position paper of the Climate Crisis Advisory Group (CCAG):[3]

"The latest assessment from the IPCC indicates that around 320 billion tonnes (Gt) of CO2 can be emitted from the beginning of 2022, to have a 67% chance of staying below 1.5°C, and 420 Gt can be emitted for a 50% chance."

With current emissions running at c.40 billion Gt per annum, this gives eight years of budget left before we exceed the budget for keeping below 1.5˚C of warming. This budget is probabilistic, though, giving a 2/3 chance of success and so a 1/3 chance of failure. Given the risks associated with exceeding 1.5˚C of warming, these are not wise odds.

CCAG go on to summarise the level of uncertainty associated with these carbon budgets and the very real risk that they may be smaller than advertised, even for these relatively low probabilities of success:

"There are a large number of uncertainties that impact upon estimates of the remaining carbon budget. The figures above assume strong action on non-CO2 emissions, no big shift in the AMOC, and that we do not cross any unexpected tipping points; in other words, no surprises. Further, this would only provide a certain probability of remaining below 1.5°C: there is a possibility that the remaining carbon budget for limiting warming to 1.5°C is already zero."

... there is a possibility that the remaining carbon budget for limiting warming to 1.5°C is already zero.

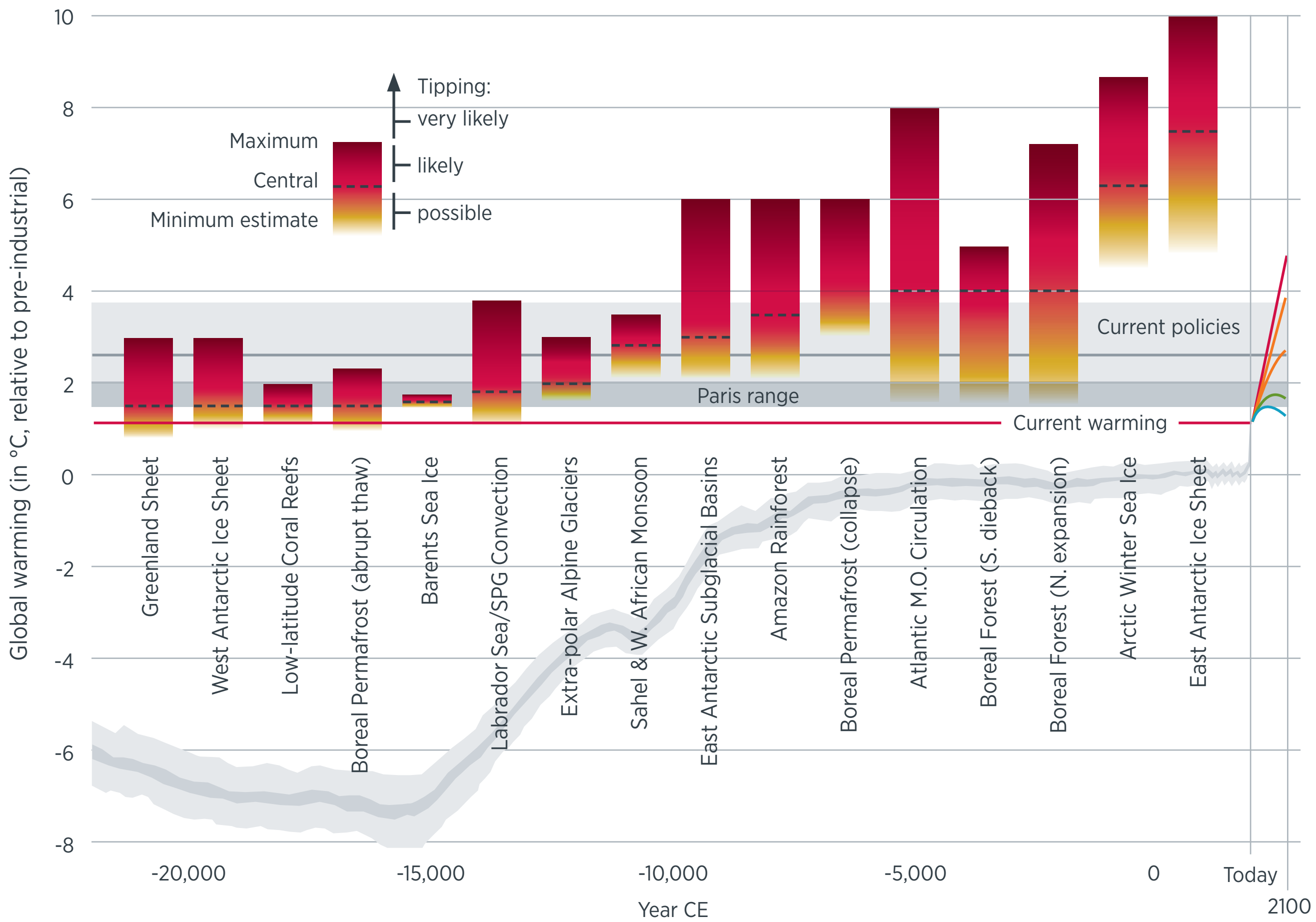
But these underlying assumptions do not hold. There has not been strong action on non-CO2 emissions, methane levels are at an all-time high (at a little over 1˚C of warming), tipping points have been partially triggered, and deforestation equivalent to adding the annual emissions of India is taking place. The consequences of these are to effectively either reduce the probability of success for a given carbon budget or to reduce the carbon budget for that probability of success.

The emergence of climate tipping points

Further non-linear impacts may be driven by multiple climate-change tipping points, which are not currently 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 halting major ocean current circulation.[4]

These tipping points may interact, triggering each other and cascading like dominoes. Once triggered they may be irreversible and would act to accelerate global warming (by increasing GHG levels) and increase the severity of impacts (eg accelerating multi-metre sea level rise). There are early indicators that we are now approaching some of these tipping points, as illustrated in *Figure 4* below, taken from 'Exceeding 1.5°C global warming could trigger multiple climate tipping points'.[5] Tipping points are particularly important as, if triggered, we may find the climate moves into a different state that we no longer have the ability to control.[6]

Figure 4: The likelihood of tipping points being triggered for different global warming temperatures



Source: McKay et al, Exceeding 1.5°C global warming could trigger multiple climate tipping points, 2022. Reproduced with permission.

The implications of tipping points include an impact on carbon budgets (they are likely to be smaller than currently assumed if we are to avoid tipping points) and accelerated, or more severe, climate impacts emerging at lower temperatures than previously thought. Consider the impact of just two of these tipping points in combination: glacial melt in mountainous regions and faster than expected sea level rise. In the region of two billion people rely on meltwater from the third cryosphere – the Himalayan icecap – 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.[7] 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.

The latest science on tipping points reinforces the need to race to zero and makes decarbonisation scenarios that feature temporary overshoot (ie allowing the temperature to increase beyond 1.5˚C before reducing it again) significantly more risky. Tipping points must be included if scenarios are to be realistic. They are no longer high-impact, low-likelihood events but are now high impact, high likelihood, and we need to mitigate and plan for them. Ignoring them in scenarios and modelling significantly understates risk.

Inconsistencies and counter-intuitive results in scenario output

The severe physical impacts of higher levels of warming mean that it is overwhelmingly economically positive to limit global warming to 1.5˚C.[8] However, climate-change scenario modelling results can vary wildly. Three different credible institutions estimate the impact of a hot-house world on global GDP by 2100 as ranging from -73%, to a milder -18%, to ongoing GDP growth, which is counter-intuitive given the severe physical risks we anticipate if temperatures continue to rise.

Climate scenarios are roadmaps that show us how the future might evolve, including ways in which we could reach net zero. Many show that it will be extremely challenging to reach net zero in the timelines that we aspire to. Appendix A of the United Nations Environment Programme Finance Initiative's (UNEP FI) *2023 Climate Risk Landscape*[9] provides a list of commonly used scenario providers, including the Intergovernmental Panel on Climate Change (IPCC),[10] NGFS,[11] the International Energy Agency (IEA),[12] and others.

The IPCC's *Sixth Assessment Report* explores future scenarios known as the shared socioeconomic pathways (SSPs). Creating these scenarios is inherently complex, requiring estimates of population, emissions, growth and the use of many integrated assessment models (IAMs) – a diagram of the process and inputs is shown in **Appendix B** to illustrate this. Key aspects of the scenarios are shown in *Table 1* below. Note again the overlap in temperature ranges.

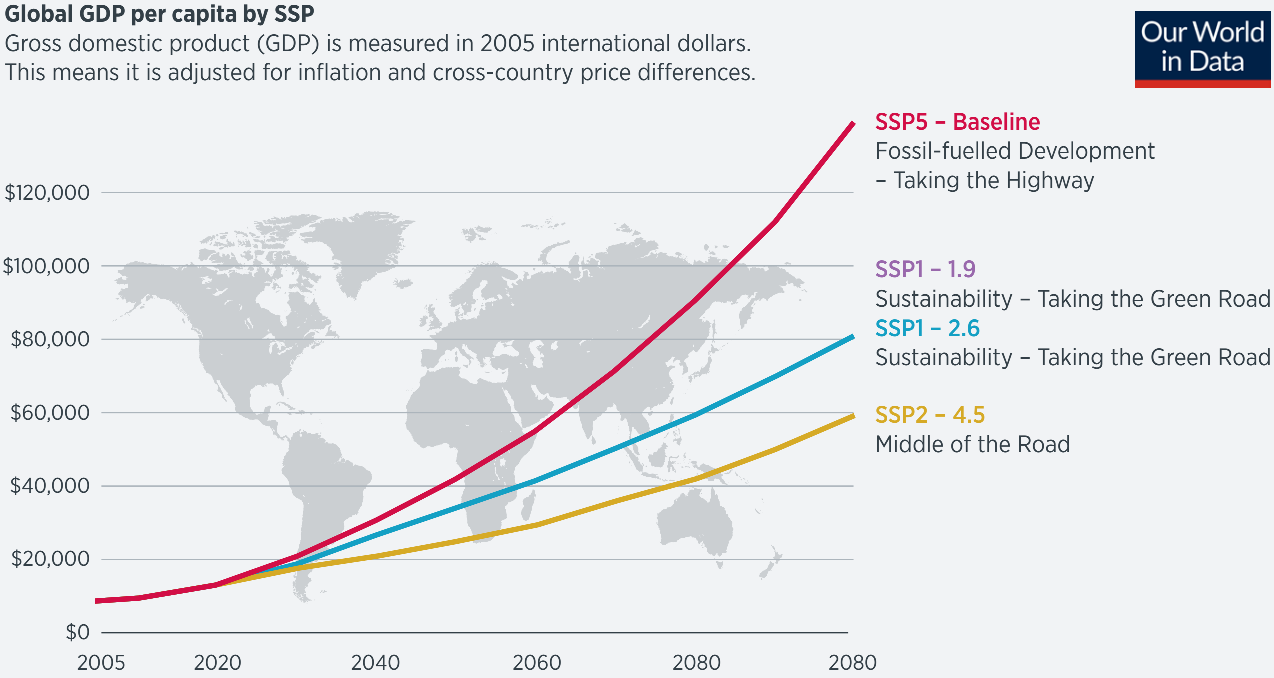
SSP5 is a scenario that foresees fossil-fuel development and high levels of global warming reaching 4˚C by 2100 and requiring the use of solutions such as geoengineering. The frequency and severity of physical risk impacts from this high-emissions pathway include increases in heat stress, extreme weather (including heavy precipitation), more frequent droughts, higher sea level rise, and a greater chance of triggering further climate tipping points.

Table 1: A summary of temperature rise statistics from IPCC reports

Scenario	Temp rise 2100 (°C) (50th (5th-95th) percentile values)	Peak temp rise (°C) (50th (5th-95th) percentile values)	Likelihood of staying below (%)			2000 year sea-level rise
			<1.5°C	<2°C	<3°C	
SSP1-1.9 (very low)	1.3 (0.8-1.5)	1.6 (1.3-1.6)	38	90	100	2-3m for 1.5°C
SSP1-2.6 (low)	1.6 (1.1-1.8)	1.7 (1.4-1.8)	20	76	99	
SSP2-4.5 (intermediate)	2.7 (2-2.9)	2.7 (2-2.9)	0	8	71	4-10m for 3°C
SSP3-7.0 (high)	3.5 (2.5-3.9)	3.5 (2.5-3.9)	0	0	22	12-16m for 4°C
SSP5-8.5 (very high)	4.2 (3.3-5)	4.2 (3.3-5)	0	0	4	19-22m for 5°C

Temperature rise and likelihoods are taken from Table SPM.2 of the AR6 WG3 Summary for Policymakers and are relative to 1850-1900 baseline. Sea-level rise taken from Table 9.10 of the AR6 WG1 Full report with the sea-level rise for a given temperature matched to the nearest scenario.

Figure 5: Global GDP per Capita by SSP



Source: Riahi et al, **The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview,** licensed under **CC BY 4.0**.

However, as shown in *Figure 5* above, this scenario predicts the highest global GDP, which is incorrect, given the physical impacts anticipated.

A comparison with other scenario-modelling results reveals inconsistencies, with some providers showing the most severe negative GDP impacts in the highest-warming scenarios. NGFS states that 'for all scenarios and time scales, physical risks outweigh transition risks.'[13] In a current policies scenario (3.2˚C of warming), NGFS estimates a reduction in global GDP of 18% by 2100 but caution that this does not include 'impacts related to extreme weather, sea-level rise or wider societal impacts from migration or conflict', all of which it estimates would act to further reduce global GDP by 2%. Adaptation costs are likewise excluded. Other limitations of the IAMs underlying NGFS scenarios include reliance on carbon prices as the exclusive policy lever, which fails to capture the full impacts of policy tools, and not accounting for the role of the financial sector (including feedback between finance and real economy transition) in mitigation pathways.

In a joint paper with the IFoA, Ortec Finance provide a more severe estimate of impacts, citing a negative GDP impact of 73% in the event of a failed transition.[14] Cambridge Econometrics, whose model Ortec Finance use, estimates that a 4˚C temperature rise would result in a 65% negative impact to global GDP by 2100.[15] Again, the authors advise that this is likely to be an underestimate as it does not account for tipping points or other unprecedented changes in the climate system. The International Monetary Fund's *World Economic Outlook Report, October 2022*[16] reinforces this message, urging policymakers to establish credible and irreversible climate policies and stating that the costs of transitioning would be 'dwarfed by the innumerable long-term costs of inaction'.

Further analysis is provided by WTW's Thinking Ahead Institute in 'Pay now or pay later'[17] where they estimate that *"If climate tipping points, that could magnify the costs of inaction, are considered we could see a 50-60% downside to existing financial assets in a business-as-usual scenario where climate risks are not addressed. In contrast, taking action to transition to a well below 2°C world might lead to a loss of 15% of existing assets which could be partly offset by the positive benefits from new primary investment."*

2: Climate scenario modelling goes mainstream

Climate-change scenario modelling is now increasingly mainstream in financial services. Financial regulators across the world are mandating that regulated entities carry out climate-scenario modelling and produce TCFD disclosures. Financial institutions are developing their capabilities to support risk management and disclosure.

Financial regulators and central banks from 31 nations have used climate-change scenario modelling to assess impacts on their economies and financial systems. This is supported by a climate-scenario modelling support ecosystem worth hundreds of millions of dollars a year.

However, closer examination shows firms largely rely on outsourced model providers, many do not yet fully understand the limitations of the models they are using, and in some cases firms are making public disclosures that raise significant questions – showing benign economic results in high physical-risk scenarios, consistent with those detailed in the previous section. These outputs may provide false comfort to institutions and advisers. They may be particularly dangerous for regulators seeking to understand systemic risk, as an aggregation of benign results may result in misplaced confidence regarding the threat of climate change to financial resilience.[18]

> ...over 80% of firms are now undertaking climate-scenario analysis, an increase of over 30% since the 2019

Snapshot of market practice – use cases and commonalities

The Global Association of Risk Professionals (GARP) has carried out four global surveys of climate-risk management at financial firms, providing a useful summary of market practice.[19] The 2022 survey showed that over 80% of firms are now undertaking climate-scenario analysis, an increase of over 30% since the 2019 survey result, when under half of firms surveyed had carried out scenario analysis. A significant driver of this is regulatory expectations, with GARP stating that: *"Nearly 90% of firms report that their regulators have published formal expectations for climate risk management, while nearly 80% say that regulators are now requiring them to report their climate-related risks."*

GARP collaborated with an industry working group sponsored by UK financial regulators – the Climate Financial Risk Forum (CFRF) – to provide more detailed analysis on climate-change scenario analysis based on GARP's survey results for 51 firms, published in October 2022 by the CFRF.[20] This showed that:

- **Firms are using scenarios to assess financial impact and risk identification**

  95% of firms surveyed use the scenarios to assess the financial impact of climate change, with 80% of firms using them for risk identification.

- **Firms are using a range of time horizons, including shorter one to five years**

  Nearly 60% of firms used shorter term (one to five year) time-horizon scenarios and 80% use medium (five to 10 year) time horizons as well as longer time horizons.[21]

- **The most commonly used scenarios are NGFS orderly, disorderly and hot house**

  A range of scenarios are used across the industry including NGFS, IEA, Representative Concentration Pathways (RCPs),[22] SSPs and regulatory scenarios. 11% of companies use 'other' scenarios, suggesting a level of sophistication in scenario design and choice.

  The most commonly used scenarios for transition risk are NGFS (orderly, disorderly, hot house). The most commonly used scenarios for physical risk are RCP8.5, NGFS hot house and regulatory defined scenarios.

- **Scenario choice is driven by the Paris Agreement, current trajectory and regulators**

  70% of firms selected scenarios that covered risks that could arise if the Paris Agreement is met, with 60% selecting scenarios expected to cover current policy and business environment risks, with around 55% using a regulatory driven scenario.

- **2/3rds of firms are now using a baseline scenario to assess impacts**

  A significant increase was observed in the number of firms using a baseline scenario against which to assess impacts, with 65% of firms using a baseline compared with 38% in the previous year. Of these, around 20% had developed their own baseline, a similar number used a regulatory scenario, and around 17% used a regulatory scenario.

When the regulatory scenarios require a substantial amount of effort, this can contribute to the perception that they are the gold standard in climate-scenario modelling, even when the regulators themselves point out the weaknesses and areas for further improvement. Further, the effort required to carry out the complex calculations can mean there is less time for management education, interpretation and understanding.

The scenario modelling ecosystem

The United Nations Environment Program Finance Initiative (UNEP FI) *2023 Climate Risk Landscape*[23] provides a thorough overview of climate-change scenario modelling practices for physical and transition risk in financial services. As well as providing details on current practices and areas of development, including the trend of aggregation in this sector, the report provides an overview of climate-change scenario model providers, listing 16 transition-risk solution providers and 19 physical-risk solution providers.

The report is clear eyed on the limitations of climate-change scenario modelling, stating that:

> *"There are certain challenges and limitations that these tools might never be able to overcome because of the uncertainty of climate change or because of the limitations of modelling and data."*

The report also makes clear that solution providers have made significant efforts to improve their transparency, with many now providing extensive documentation of models, alongside training.

Models users must choose from a wide variety of solutions

While the UNEP FI report was largely driven by banking, scenario analysis is becoming ubiquitous in financial services sectors, with pension schemes, insurance companies and asset managers also developing their capabilities, driven by a combination of business needs, client and regulatory demand.

In developing their approach, firms must make decisions on which climate risks they are most interested in (physical or transition – recognising these are not independent) and the model methodology, 'top down' or 'bottom up'. With top-down modelling, firms seek to estimate the impact of climate scenarios on global GDP, then national GDP and finally asset class returns. Bottom up seeks to model the impact of climate change on individual companies or assets, before aggregating this into an overall portfolio position. In this paper, our focus is on top-down modelling of climate change physical risk, particularly focusing on the hot-house world scenario, although the principles of understanding limitations and assumptions apply equally to bottom-up modelling and transition risk. Other institutions are publishing on climate-change scenario limitations and assumptions, for example the UK Centre for Greening Finance and Investment.[24]

A small number of anonymised samples is shown opposite in *Table 2*, taken from public TCFD disclosures from regulated entities, that show the estimated impact on portfolio values of different climate scenarios.

In displaying these, our intention is not to target any particular methodology or climate-scenario provider. It is illustrative, to show the jarring disconnect between climate science and financial services. We explore the reasons for this disconnect in **Section 3**.

There is a disconnect because there is no plausible future without global warming. The economics of the energy transition suggest its inevitability. However, we model the impact of various climate scenarios against a base case of no global warming and no energy transition.[25] But climate science and in particular the emergence of tipping points suggest there is a level of warming that will cause a very significant loss of GDP.[26] We explore an alternative approach that would reflect this reality in **Section 4**.

Sample of publicly disclosed TCFD results from major UK investors

No comprehensive sample of TCFD results has been undertaken. All the institutions that these results are taken from have committed to net zero and demonstrate a comprehensive understanding of climate change and the risks it presents. All these institutions stated that the hot-house world results are likely to understate physical risk, possibly significantly.

Three of the institutions surveyed did not provide quantitative results of climate-change scenario analysis, citing the limitations and uncertainties inherent in current methodologies. One institution provided ranges rather than precise figures. However, these ranges showed the disorderly transition to have a greater impact on the institution's asset portfolio (>5%) than the hot-house scenario (between 2% and 3.5% impact).

Table 2 opposite shows the percentage per annum impact of different climate scenarios on portfolio returns figures from a set of anonymised publicly disclosed TCFD reports for long-term scenarios, typically 2050 or 2060. In many cases the results for the hot-house scenario are similar to those produced for more benign temperature scenarios. Some results show that the hot-house scenario results are the most positive economically.

Table 2: Sample TCFD results from UK investors, impact on portfolio returns per annum, long term

Institution	Orderly	Disorderly	Hot House
Institution 1	-0.2%	-0.2%	-0.1%
Institution 2	-0.1%		-0.1%
Institution 3	-0.1%		-1.0%
Institution 4	0.7%		-0.5%
Institution 5	-0.1%	-0.5%	-0.4%
Institution 6	0.0%		-0.2%

In several cases, the failed transition or hot-house world scenario is shown as the most negative outcome, with some institutions providing analysis that equates this to a 1% negative impact on returns over a long time period (typically 30 or 40 years) which, all other factors being equal, would equate to a 1/3 loss in portfolio value. Other institutions show the hot-house scenario to be only slightly less economically damaging than a disorderly or orderly transition.

Given the differences in asset portfolios, underlying models and scenario specifications this analysis is necessarily limited.

3: Climate scenarios – a warning for financial services

In this section we describe at a high level the different stages of a climate model, what principles actuaries use to support reliable use of models, and how to apply these to climate modelling. We focus on top-down physical risk modelling and the hot-house scenario, although the principles apply to all modelling of climate-change scenarios.

Applying actuarial principles to climate modelling shows that the observed benign results for the hot-house scenario are the consequence of a number of significant judgements that are made throughout the modelling process. These include the specification of the chosen scenario, key climate modelling assumptions concerning how much and how quickly the planet will warm for a certain level of GHGs, a damage function that excludes many of the risks we expect to face, and the choice of economic model.

Consequently, many climate models are severely under-estimating the economic impact of climate change because:

1. Modelled scenarios do not incorporate our experience on climate change and may not be realistic when compared to experience. There is also limited consideration of higher warming scenarios.
2. There is considerable uncertainty in key climate-system modelling assumptions, including how rapidly the climate will warm for a given level of emissions, which are likely to be prudent meaning the carbon budget for limiting global warming to 1.5°C may now be exhausted. However, no margins are currently included to represent this uncertainty.
3. Damage functions that are used to estimate the economic impacts of climate change exclude many of the risks we expect to face, such as those impacts from tipping points, or societal consequences such as involuntary mass migration.
4. General equilibrium models that are widely used to estimate economic impacts contain a number of simplifying assumptions that do not hold in the real world.

We conclude that it is essential for model users to be climate literate in order to understand the context in which models are used and the limitations that apply to climate models. They should be used alongside narrative scenarios to provide direction and rank on risks – but users must not interpret results as accurate.

In particular, the observed benign results for the hot-house world are deeply flawed and underestimate the impact of the risks we expect to face.

> Many climate models are severely under-estimating the economic impact of climate change.

History is replete with incidents in which we have placed too much faith in models.

Actuarial principles

Actuaries have well-established standards that apply to 'technical actuarial work'. In the UK, the over-arching objective set for actuarial work by the Financial Reporting Council (FRC) is that it should meet the Reliability Objective, as stated in TAS100.[27] This says:

"To allow the intended user to place a high degree of reliance on actuarial information, practitioners must ensure the actuarial information, including the communication of any inherent uncertainty, is relevant, based on transparent and appropriate assumptions, complete and comprehensible."

Underpinning this is a set of principles[28] for actuarial work covering seven areas: Risk Identification, Judgement, Data, Assumptions, Models, and Communications and Documentation, which are detailed in **Appendix C**. By applying these principles to the area of climate-change scenario analysis, we can test whether current approaches meet the standards for actuarial work.

A clear theme that runs through these principles is the need to explain judgements, methodologies and assumptions, particularly where these are material and contribute to limitations or uncertainties. Actuaries themselves have been warned by external parties[29] and their profession[30] about the need to appropriately consider climate change in their professional advice, a warning reinforced by the FRC's updated Technical Actuarial Standards,[31] which specifically call out climate change as a material external factor that may influence actuarial work.

These principles are important, as they are designed to mitigate the risk of placing too much faith in models. History is replete with incidents in which we have placed too much faith in models, including the global financial crisis, the collapse of Long-term Capital Management, and, more recently, the UK pension scheme LDI crisis. A common theme is that models under-estimate the level of risk because it is mathematically tractable to do so, in some cases due to underpinning assumptions that do not hold in the real world.

Figure 6 below shows a simplified climate-change scenario modelling process.

This challenge requires significant judgements in many areas, including which scenarios to model, selection of appropriate models and methodologies, modelling linkages between the Earth's physical climate system and human society, which data sets to use to parameterise those models, and how to incorporate uncertainty.

Figure 6: The climate-change modelling process

I: Emissions

The first step is to estimate how GHGs emissions will change in the future, as this will determine the levels of atmospheric GHGs, which in turn will drive warming. This is a key specification of any climate scenario.

II: Warming

Following this, a key question is how much warming will be driven by a certain level of GHGs and how quickly this warming will happen, as this will drive the frequency and severity of the acute and chronic physical risks we expect to be impacted by. This is driven by climate models, which are parameterised to past climate-system changes.

III: Damages

Finally, we seek to estimate how much damage these physical risks will inflict – what could the impact be on individual assets, companies, countries and the global economy.

I: Emissions

Scenario choice and emissions

Most firms begin by using three climate scenarios, often those specified by NGFS or local regulators. A recent paper[32] found that the focus of IPCC reports has drifted to focus on lower temperatures over time, perhaps reflecting the focus on net zero and the goals of the Paris Agreement.

The report found that there has been relatively limited consideration of the impacts of higher temperature and, as our analysis has shown, the modelled results for a hot-house world are overly benign.

However, we are now at a point where the level of greenhouse gases in the atmosphere is double the pre-industrial level,[33] driving accelerating warming. This level of emissions is in line with the high emissions scenario RCP8.5, which the IPCC estimate would lead to over 2°C of warming by 2050. As illustrated in Section I, there is also a significant range of uncertainty associated with carbon budgets.

A faster warming planet will drive increasingly severe acute physical risks, increase the pace of chronic physical risks, and increase the likelihood of triggering multiple climate tipping points, which collectively act to further accelerate the rate of climate change and increase physical risks.

Organisations should therefore think carefully about choice of scenario, recognising that although regulatory scenarios have the advantage of providing consistency, they may not capture recent experience, may not fully reflect the risks we face, and may not be particularly realistic or even likely. Organisations must also recognise that the regulatory scenarios are not stress or tail scenarios (eg 1-in-200) that are familiar from regulatory capital requirements.

More sophisticated firms are now working with model providers to develop bespoke scenarios that they feel reflect more accurately some of the risk drivers we face into – on both physical and transition risk.

Some organisations are also developing a baseline or best estimate scenario that takes into account factors such as those described in the previous section. Qualitative narratives should be developed initially, with modelling undertaken where appropriate to do so. However, given the challenges of calibrating a model to a complex basket of never before experienced risks, users should beware of spurious accuracy – it is better to be roughly right than precisely wrong.

II: Warming

The earth's climate may be more sensitive than we thought

A simple analogy for global warming 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.

Without delving too deeply into climate science, for the purposes of climate-change scenario analysis we are interested in two key points:

A. How much the planet will warm for a given level of GHGs?

B. How quickly the planet will warm?

A. How much will the planet warm for a given level of GHGs?

Equilibrium climate sensitivity (ECS) is one of the key assumptions used to derive estimates of warming for different levels of GHGs. A short briefing on ECS provided by Carbon Brief,[34] states that ECS was first defined in 1979 in the Charney report from the National Academy of Sciences in the US. This report estimated that if we doubled atmospheric CO2, then ECS would be between 1.5°C and 4.5°C.

ECS estimates have remained remarkably stable over time, the IPCC's 2021 *Sixth Assessment Report* giving an updated range of 2.5°C–4°C, with a best estimate of 3°C. Some scientists estimate that the best estimate could be higher at 4°C due to uncertainties associated with key variables such as aerosol cooling and the rate at which ocean mixing occurs.[35]

Some scientists estimate that Earth-system sensitivity may be double ECS, after allowing for the full impact of reducing ice sheets.

A key takeaway is that an ECS of 3°C means that if we double GHGs, as we have, then we would expect the planet to warm by 3°C.

Although it is hard to be precise about what conditions we might experience once the planet warms by this amount, scientists estimate this level of GHGs to be comparable to the Pliocene period, when sea level may have been 17 metres higher, global temperatures 2˚C–3˚C higher and the poles ice free.

However, ECS has a wide range of uncertainty and as Kemp et al[36] point out, is heavy tailed, with an 18% chance of being greater than 4.5˚C.

This uncertainty is partially reflected in the overlapping temperature ranges predicted by the various RCPs (as shown in Section I, Figure 3) – with the lower temperature range of RCP8.5 overlapping the higher temperature range of RCP7, and so on.

It is also important to note that ECS is calculated without the effect of longer-term feedbacks such as changes in ice sheets and vegetation. Earth-system sensitivity, which allows for these changes, has been estimated to be significantly higher than ECS. Some scientists estimate that Earth-system sensitivity may be double ECS, after allowing for the full impact of reducing ice sheets. A full risk assessment of climate change should take Earth-system sensitivity into account and recognise that the rate of warming may be faster than we have anticipated.

B. How quickly will the planet warm for a given level of GHGs?

Climate response time (CRT) is also uncertain and hard to estimate. On the one hand, a long CRT is problematic, as the time lag between rising GHG levels and changes to the climate may be long, meaning we may not take action to reduce emissions as we are not yet experiencing the warming associated with those emissions. On the other hand, a long CRT means we have an opportunity to reduce GHG levels before the climate warms too much.

Overall, we conclude that there is significant uncertainty around the warming associated with a particular emissions scenario. It is likely that we have now exhausted the carbon budget for 1.5°C and may breach 2˚C by 2050 with the current level of GHGs in the atmosphere. If ECS is closer to the top of the range or even above it, we may already be headed for higher warming even if emissions remain in the RCP2.6 to RCP4.5 range.

Scenario users need to think through the implications of this in scenario design, as well as developing a view on what is likely as emissions continue to rise along with the global temperature.

III: Damages

Choice of damage function and economic model drives material changes in results

In this section we examine damage functions, showing that calibration choices drive very material results differences, as well as highlighting the risks excluded from these damage functions. We also examine the choice of macro-economic model, referencing analysis that shows that a driver of some counter-intuitive results is the assumptions underlying traditional general equilibrium economic models.

Damage functions exclude many of the risks anticipated to arise from climate change

As the climate continues to warm we are likely to face increased extreme weather events, changing climatic conditions driving floods and droughts, heat spikes and in the longer term glacial melt and sea level rise. We also risk triggering multiple climate tipping points which would act to further accelerate climate change or its impacts. These impacts could drive second order events such as shocks to global food supplies or involuntary mass migration.

Economists have estimated the economic losses from climate change in a hot-house scenario to be *"as low as 2.1% of global economic production for a 3˚C rise in global average surface temperature, and 7.9% for a 6˚C rise."* In the paper this quote is from 'Economists' erroneous estimates of damages from climate change'[37] Keen et al look at why this is the case, exploring the methodologies used and the striking disconnect from climate science. In particular, the methodologies used by some economists exclude many of the risks we expect to face, including those from tipping points. Further analysis of the weaknesses and limitations of IAMs is provided by Stern and Stiglitz.[38]

Any methodology based on these economic models will therefore also exclude these risks, as is the case with many current climate scenarios used in financial services. NGFS estimates a reduction in global GDP of 18% by 2100 from chronic physical risks but caution that this does not include *'impacts related to extreme weather, sea-level rise or wider societal impacts from migration or conflict. For given countries these would likely strongly increase the physical risk. These estimates also do not fully capture adaptation, which would reduce impacts but require significant investment.'*[39] Including acute physical risks increases this GDP impact to nearly 20% by 2100, although this is based on cyclones and river flood damages, rather than all physical risks. This is a significant increase from its previous estimate of a 6% reduction in global GDP, which NGFS recognises was too conservative.

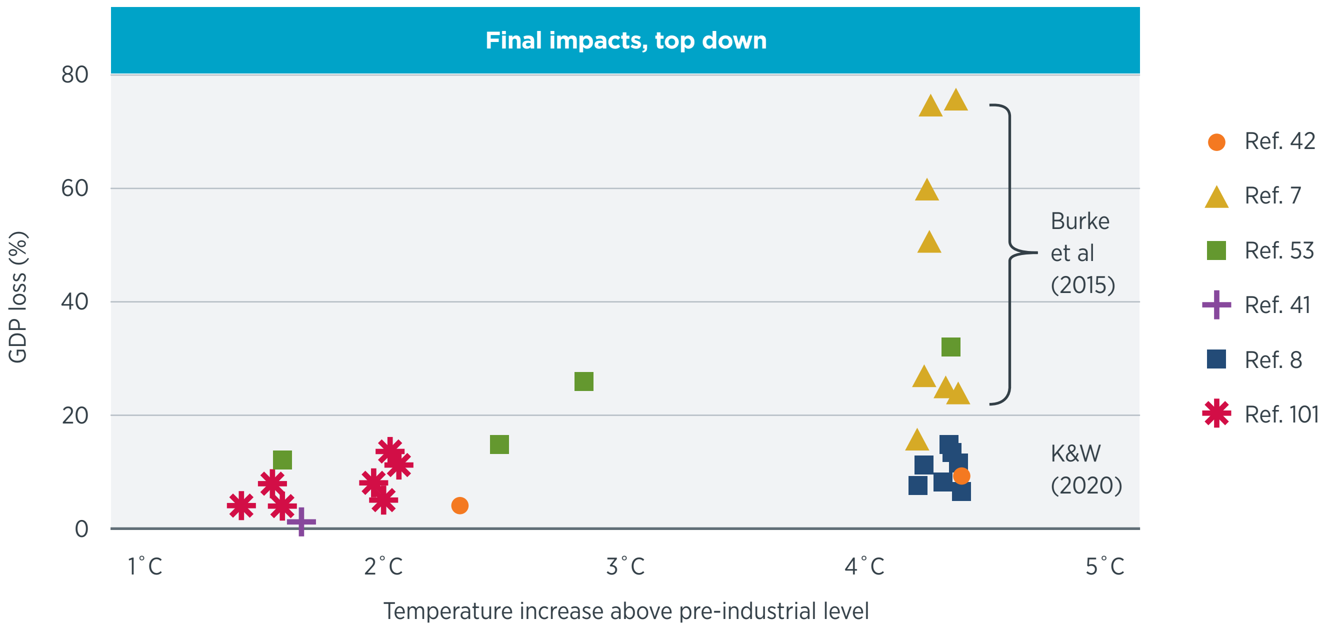
Indeed, NGFS has reiterated this point by issuing a joint statement with the Financial Stability Board (FSB)[40] on 15 Nov 2022, pointing out that scenarios derived from NGFS scenarios (which include Climate Biennial Exploratory Scenario (CBES) scenarios) may understate climate exposures and vulnerabilities.

This damage function is not distributed evenly across economies – some equatorial countries face GDP impacts of over 30% while some Northern Hemisphere countries face impacts of less than 10%. This is because NGFS damage functions are calibrated to an academic paper (Kalkuhl & Wenz 'KW', 2020) that estimates the impact on productivity of higher temperatures on GDP level but, as stated above, does not capture other risks.

An alternative academic paper (Burke-Tanutama 'BT', 2019) provides higher estimates for gradual physical shocks to GDP and is used to underpin the Cambridge Econometrics model. The BT approach assumes a higher temperature level has a negative impact on GDP growth, as well as GDP level, which is why GDP impacts are higher than KW's – as GDP level is negatively impacted as well as growth. However, this approach still excludes many of the risks detailed in the previous section, such as tipping points, because it works from historical data still giving a conservative estimate of the damage function.

Figure 7 below, from 'Integrated perspective on translating biophysical to economic impacts of climate change'[41] shows a comparison of results for global GDP loss due to temperature rise, using the BT and KW methodologies for the Failed Transition scenario. The KW paper leads to a 10% global GDP loss, compared to a 63% GDP loss by 2100 using BT, although by 2050 the two approaches are closer, 2% vs 10%.

Figure 7: Comparison of GDP losses by 2100 based on two different methodologies



Source: Piontek et al, 'Integrated perspective on translating biophysical to economic impacts of climate change', 2021. Reproduced with permission.

In summary, commonly used loss functions are based on past data and exclude many of the risks we expect to face. Choice of loss function has a very material impact on results – varying from 6% to 18% to 63% loss in global GDP by 2100. The NGFS estimate of 20% (including acute physical losses) should be viewed as a conservative lower bound for expected GDP losses we should expect if we do not change course.

Macro-economic model choice has a very significant impact on results

Public reference scenarios, including the NGFS, rely on models referred to as computable general equilibrium models (CGE). CGE models were created by the climate-science community to inform high-level public policy making. Traditionally, they have been used to assess the socio-economic impacts of various climate pathways. The macroeconomic modules of these models had a very different use case from how the financial sector is currently applying them. They have some simplifying neoclassical economics assumptions which generate outputs that do not adequately capture real-world economic dynamics, such as:

- Individuals act only in their own self-interests and are dedicated to maximising their utility
- Individuals have perfect knowledge and perfect foresight and use this information to calculate all possible outcomes and optimise their decisions
- CGE models results are presented as long-term outcomes, without considering possible upheaval or length of the transition process
- Money is 'neutral'(required only to facilitate real transactions) and fixed in supply.
- Banks are treated merely as intermediaries, failing to recognise their role in money creation.[42]

Non-equilibrium models, such as the post-Keynesian E3ME model maintained by Cambridge Econometrics, still have limitations but are designed to simulate real-world economic dynamics more accurately. For example, actors are not assumed to be all knowing, perfectly efficient entities but derive behavioural parameters from historical relationships. Also, money can be created by banks through new loans and this investment is not crowded out. Further analysis on this is provided in an article in The Actuary magazine from March 2022,[43] which emphasises how significant model choice is on results.

Non-equilibrium models, such as the post-Keynesian E3ME model maintained by Cambridge Econometrics, still have limitations but are designed to simulate real-world economic dynamics more accurately.

4: A new beginning

“A model might show you some risks, but not the risks of using it. Moreover, models are built on a finite set of parameters, while reality affords us infinite sources of risks.” [44]

Nassim Nicholas Taleb was not describing climate-change scenario modelling when he used these words but they are applicable nonetheless. Climate change is complex, nuanced and characterised by deep uncertainty – and it is essential that model users understand this – as well as developing their understanding of how climate risks could impact their models.

To address this, further work will be required on both quantitative and qualitative fronts. We suggest a possible way forward below.

Qualitative – rich narrative scenarios

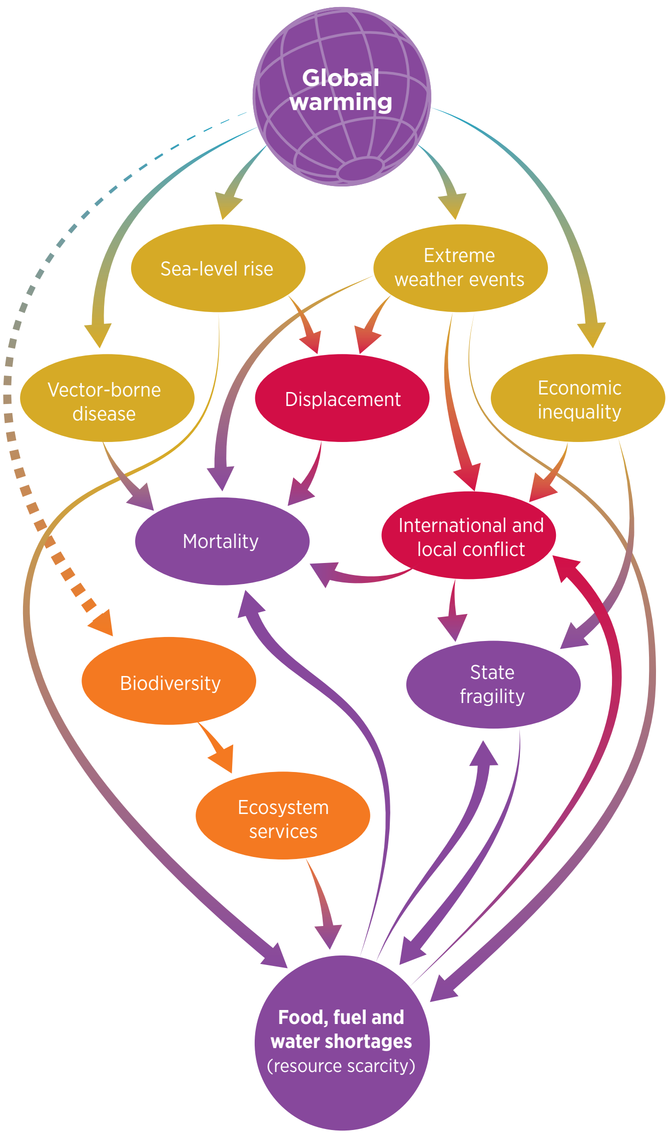
As illustrated in *Figure 8* opposite from ‘Climate Endgame: Exploring catastrophic climate change scenarios’,[45] global warming will impact a number of interconnected risk drivers, which in turn will impact factors that influence financial markets and financial institution solvency. Firms should develop qualitative scenarios that explore how these risks could cascade and what actions could be taken.

Visualisations of climate impacts can be helpful to drive debate and illustrate potential future scenarios, such as flood maps showing the difference between areas that will be inundated in a 1.5˚C degree scenario compared to a 4˚C degree scenario. See, for example: **https://coastal.climatecentral.org/** and further thoughts on approach in **Appendix A.**

Quantitative – a new baseline and an updated loss function

A practical fix may be to ‘invert’ scenario analysis and use a reverse stress test approach, as used in financial services risk management. This would start with what we want to avoid, then work backwards from there. Rather than carrying out climate-scenario analysis against a fictional world in which climate change is not happening, we could work from a new baseline of achieving the net-zero transition. This is the best outcome we can hope for and resolves the issues of having a baseline that assumes neither climate change nor the energy transition is happening.

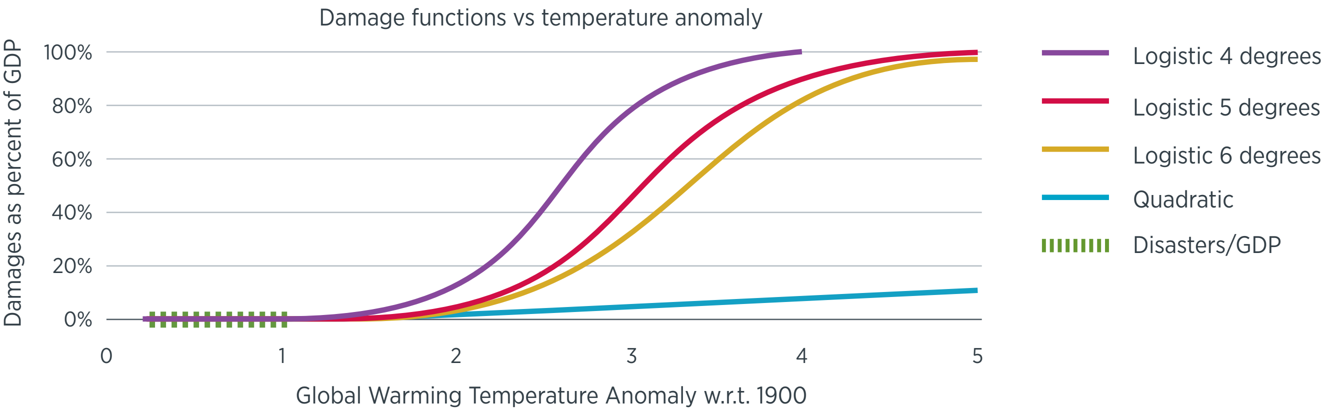
Figure 8: Cascading global climate failure



Source: Kemp et al, ‘Climate Endgame: Exploring catastrophic climate change scenarios’ (2022). Licensed under CC by 4.0.

Climate change is complex, nuanced and characterised by deep uncertainty – and it is essential that model users understand this.

Figure 9: Climate damage functions – % GDP loss vs temperature



Source: Carbon Tracker (forthcoming), Keen et al, IFoA analysis. Reproduced with permission.

A relatively simple log damage function could be used that assumes 100% GDP loss at a certain level of warming, say 6˚C, 5˚C, or 4˚C, although some may argue that even 3˚C would be extremely challenging to adapt to, and certainly sensitivities should be undertaken at all of these.

Figure 9 above, adapted from analysis undertaken by Carbon Tracker, illustrates this, as well as comparing the output with the current quadratic damage function used by economists.

The quadratic damage function is what underpins the economic models described in previous sections. This is based on damages in the future being an extrapolation of damages in the past 'when it got a bit warm'. This damage function excludes tipping points and many of the risks we expect to face. As observed from the graph, this damage function does not show significant GDP losses, even at 5˚C of warming.

The logistic damage function assumes total economic destruction at c.6˚C but close to total at 5˚C, based on analysis provided by Carbon Tracker. This approach does not explicitly model the impact of the various risks we will face, 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.

The red and orange lines 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 some human population with associated residual economic activity.

Three key assumptions are needed, which are:

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

ii. What the rate of warming will 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, then 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 results than the benign hot-house world disclosures we currently see, and is arguably more valuable in terms of considering the possible implications of adverse scenarios.

There is uncertainty around how much warming we will experience. As described in the previous section, atmospheric GHGs are now double their pre-industrial level, which is what ECS is calibrated to. A reminder that best estimate ECS = 3˚C but there is an 18% chance that ECS>4.5˚C.

Earth-system sensitivity is greater than ECS, as ECS assumes ice sheets and vegetation fixed, with a possibility that ESS is significantly greater than ECS. Conservatively, there is an argument for at least a 20% chance that we may be on a trajectory to 5˚C or more of warming at current levels of GHGs.

The pace of warming is also uncertain. However, some scientists now estimate warming of 0.3˚C per decade or around 1˚C every 30 years, which would imply warming of greater than 2˚C by 2050 and 3˚C by 2080. This is well within life expectancy for many in workplace schemes now and in range for the European Insurance and Occupational Pensions Authority (EIOPA) who have specified 80 years as long range for the Own Risk and Solvency Assessment (ORSA).

Put another way, at what point do we expect 50% GDP destruction – somewhere between 2070 and 2090 depending on how you parameterise the distribution. It is worth a moment of reflection to consider what sort of catastrophic chain of events would lead to this level of economic destruction.

This analysis provides a compelling logic for net zero becoming part of fiduciary duty, as if we do not mitigate climate change, it will be exceptionally challenging to provide financial returns.

… at what point do we expect 50% GDP destruction – somewhere between 2070 and 2090 depending on how you parameterise the distribution.

Appendix A

Example qualitative, narrative scenario

A complementary approach is to provide a narrative scenario, especially where quantitative scenarios are ill-equipped to effectively model the impacts of tipping points and the cascading effects of climate change. Instead, descriptions can be helpful for decision-makers to understand the potential impacts of a hot-house world for companies and investors. One area of financial risk that has previously been articulated is the impact of climate change on the insurance sector – insurability is not limitless and comes at a price. Insurance leaders have unequivocally stated that if climate change raises average temperatures to 4˚C above pre-industrial levels most assets will be uninsurable.[46] Without insurance, investment, finance, business slow to a halt – we will no longer have an economy. Governments will no longer have a tax base from which to deliver vital services or repay coupons on gilts.

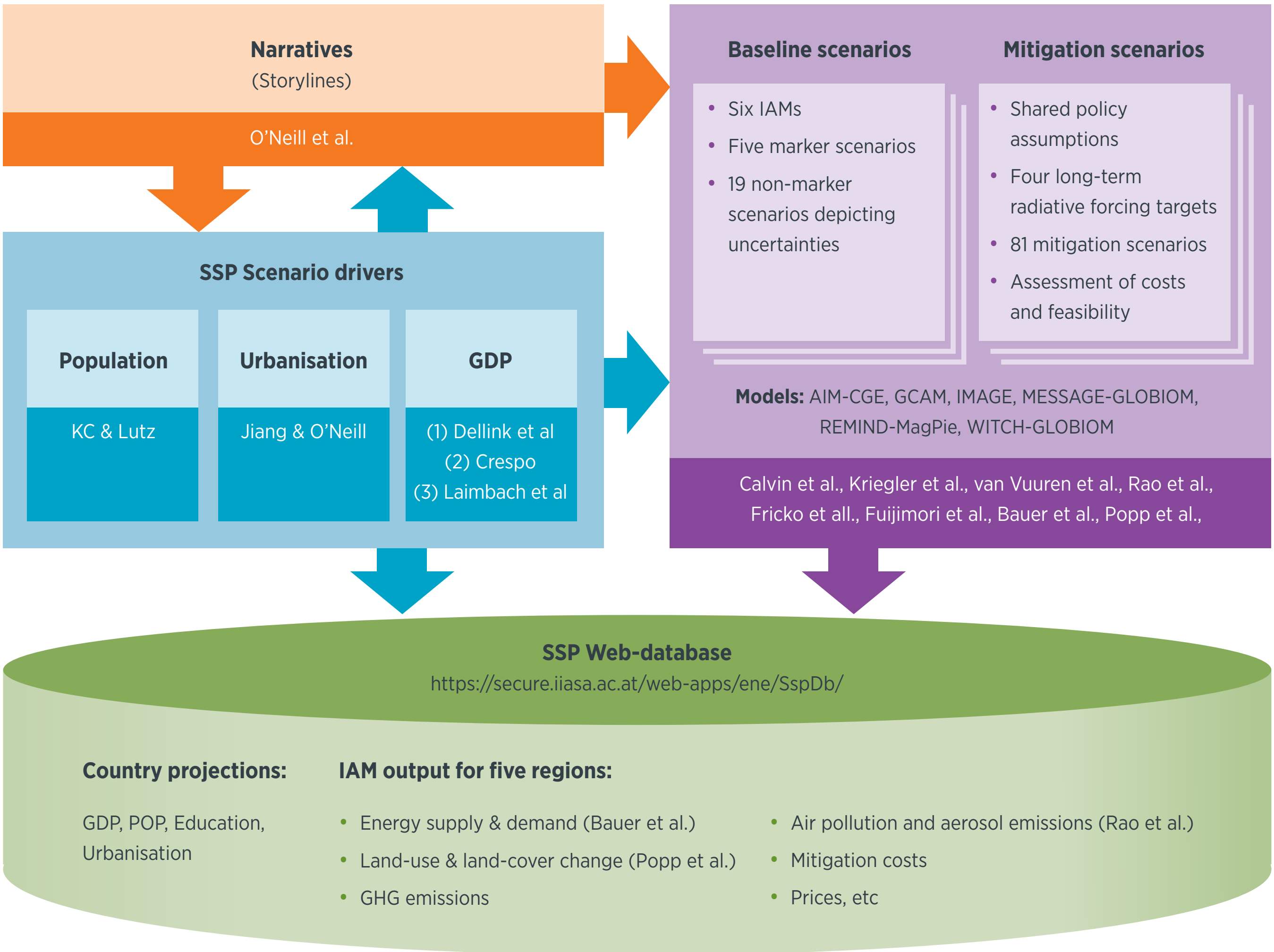
Using visualisations, we can also look at the physical, land use and population movement impacts to consider the potential change to our Earth's regions in terms of productivity and habitability. Through these narratives and visualisations, we can consider the impacts a 4˚C rise would have on business and investments. For example, Climate Central[47] is a website that provides visualisations of sea-level rise, showing land that is projected to be below the tideline by 2050. This in turn can be used to inform estimates of involuntary mass migration, which can help decision-makers take the actions they need to today to avert this potentially financial and human disaster.

> Insurance leaders have unequivocally stated that if climate change raises average temperatures to 4˚C above pre-industrial levels most assets will be uninsurable.[47]

Appendix B

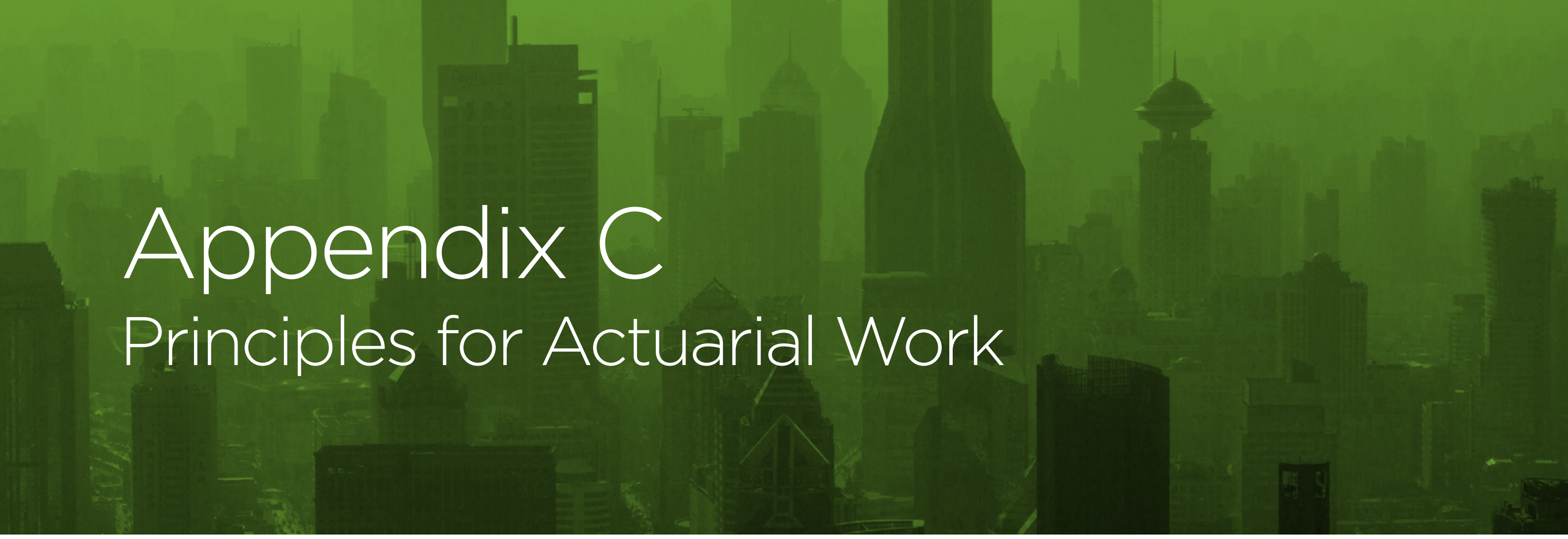
SSP creation diagram

Figure 11: Schematic of process for creating Shared Socioeconomic Pathways



Source: Riaha et al, 'The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview', 2017. Licensed under CC BY 4.0

The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview - ScienceDirect



Appendix C

Principles for Actuarial Work

General Actuarial Standards - Version 2.0 **(frc.org.uk)**

- **Risk identification**
  Practitioners carrying out technical actuarial work must identify and consider all relevant material factors and relevant material risks that may affect or have the potential to influence their technical actuarial work and which the practitioner might reasonably be expected to know about at the time of carrying out the work.

- **Judgement**
  Practitioners must exercise judgement in a reasoned and justifiable manner, so that the intended user can rely on the resulting actuarial information.

- **Data**
  Practitioners carrying out technical actuarial work must seek to ensure data is sufficiently accurate, complete and appropriate, so that the intended user can rely on the resulting actuarial information.

- **Assumptions**
  Assumptions used, or proposed for use, by practitioners in their technical actuarial work must be appropriate, so that the intended user can rely on the resulting actuarial information.

- **Models**
  Practitioners must ensure models used in their technical actuarial work are fit for purpose and subject to sufficient controls and testing, so that the intended user can rely on the resulting actuarial information.

- **Documentation**
  Practitioners must ensure documentation relating to their technical actuarial work contains sufficient detail to enable technically competent persons responsible for reviewing or providing assurance in relation to the technical actuarial work to understand the matters involved and assess the judgements made.

- **Communications**
  Practitioners' communications must be clear, comprehensive and comprehensible, so that the intended user can reasonably be expected to understand matters relevant to actuarial information and make informed decisions.

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