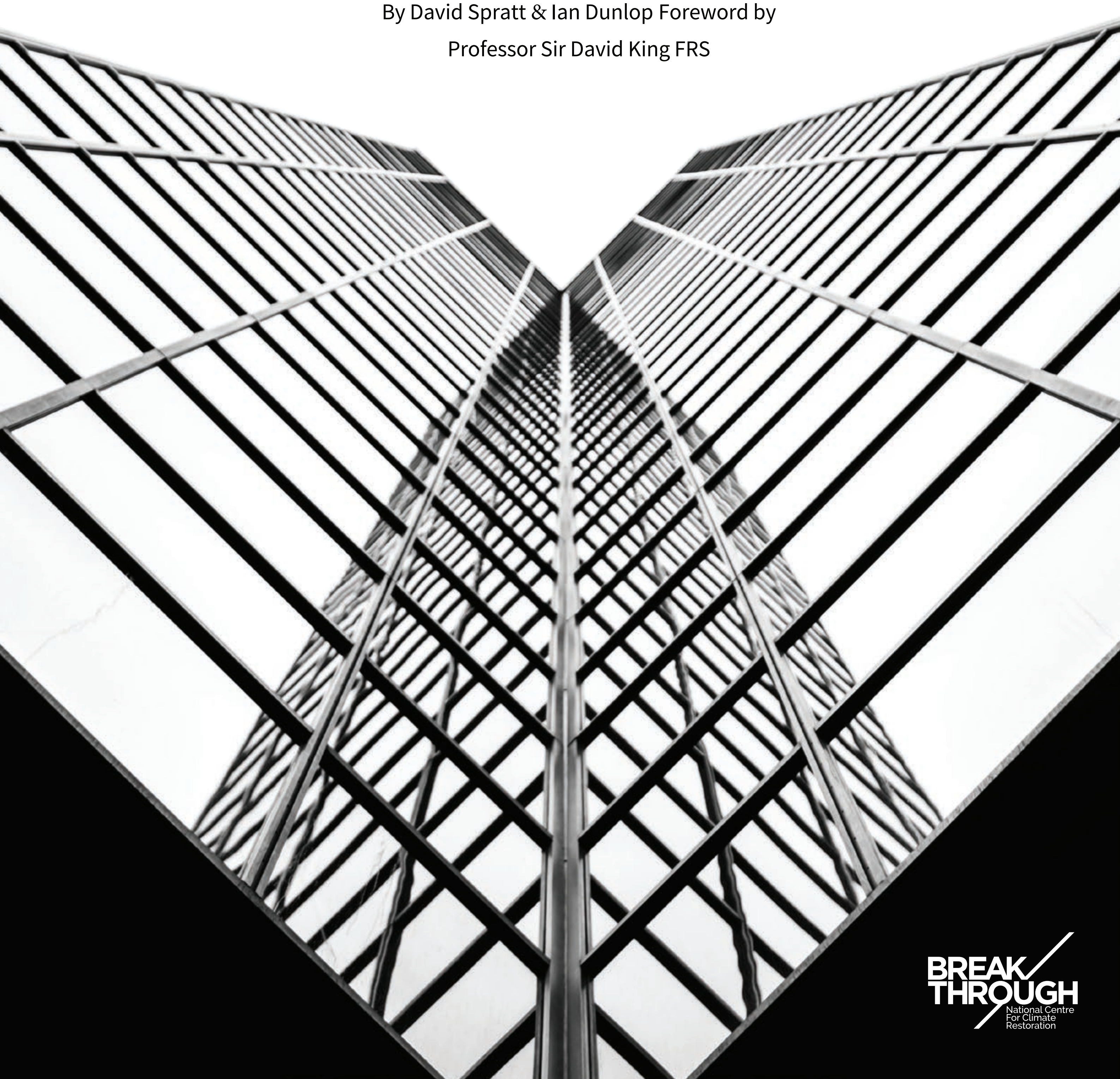
DEGREES OF RISK

Can the banking system survive climate warming of 3˚C?

By David Spratt & Ian Dunlop Foreword by
Professor Sir David King FRS



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FOREWORD

Since climate negotiations began in Rio in1992, and despite the 1997 Kyoto Protocol and the 2015 Paris Agreement, little has been achieved. There is a continuing upward trend in global carbon emissions, rather than the rapid decrease necessary if escalating climate impacts were to be avoided.

Today the level of greenhouse gases (GHGs) in the atmosphere is already so high that rapid emissions reduction is no longer sufficient to avoid an unmanageable future for mankind. We also must have the capability to remove GHGs at scale from the atmosphere, and to repair those parts of the climate system, such as the Arctic, which are passing or have passed their tipping point.

In recent years, as the scientific projections and the evidence have accumulated, concerned scientists and institutions have called for emergency action to address the climate change threat. These calls were picked up widely by communities worldwide in 2019, but are still largely unheeded by political and business leaders.

That is beginning to change as the very real human and economic costs of climate change mount, for example in the unprecedented 2019-20 Australian and Californian bushfires, floods in China and extreme temperatures in India. Even greater extremes are occurring this year in the Northern Hemisphere; in Western USA, Canada, the Arctic, Siberia, the Mediterranean and the Amazon. Many climatic changes are already occurring which scientists had not anticipated until later this century.

National and supranational regulators, with their independent mandates, have been more attuned to these risks than most, and aware of the threat to the stability of the global financial system. The result has been notable initiatives such as the Financial Stability Board's Task Force on Climate-related Financial Disclosure, and the Network for Greening of the Financial System -- set up by several central banks — which have been instrumental in forcing the business and financial worlds to take climate risk more seriously.

Their most recent work, to standardise climate scenario analysis, is encouraging the institutions they regulate to stress test their future activities, implying that global mean warming scenarios of up to 3–4°C might be manageable, and with implicit support for net zero emissions by 2050 policies.

However, as *Degrees of Risk* argues, 3–4°C warming is a threat not just to the banking system, but to the very survival of human civilisation. It is beyond adaptation, and achieving net zero emissions by 2050 is far too late.

Regulatory institutions exert great influence in the framing of financial markets and corporate responses to climate change. It is critically important their deliberations clearly incorporate and communicate the risks and uncertainties implicit in the climate science. If their recommendations are built on unrealistic assumptions, failure to properly address climate change becomes institutionalised, and that we cannot afford.

Degrees of Risk clearly articulates the need for regulators to revise their approach: understanding and disclosing the risks is not enough, the need now is to act on them. It is the short term which matters most. What global leaders do in the next three-to-five years will determine the future of humanity.

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Note: A glossary of terms is on page 30.

OVERVIEW

- To make climate risks more transparent, central banks and regulators globally are undertaking stress tests of the financial system. Most notable have been initiatives by the Task Force on Climate-related Financial Disclosures (TCFD), the European Central Bank and the scenario work of the Network for the Greening of the Financial System (NGFS). In Australia, regulators have coordinated their work through the Council for Financial Regulators, with the Australian Prudential Regulatory Authority initiating a climate vulnerability assessment for banks, encompassing scenarios up to 3°C of global mean warming, and issuing draft guidance for companies to stress test their own finances against scenarios up to 4°C warming.
- In considering the response of financial markets to the threat of climate change, lessons may be learnt from the 2008 Global Financial Crisis, where scenarios, modelling and stress testing failed to foresee the crisis and the consequences for the banking system, investors and business more broadly.
- Stress tests are simulations, relying on scenarios of future circumstances, and on models of the climate, the economy and the financial system that are subject to severe limitations, especially for events many decades into the future. These limitations include non-linear processes, cascade effects and radical uncertainty, where probabilities cannot be attached to specific outcomes or used with confidence.
- It is particularly challenging to map first-order physical climate warming effects onto the second-order impacts in the social and financial spheres because it depends on the responses of complex human systems which cannot be reduced to probabilistic terms. In a complex world, systemic risks can arise from interactions between changes in the physical climate and human systems, so that small changes can lead to large divergences in the future state.
- Scenario analysis creates coherent, credible stories about alternative futures, allowing for constructive discussion on alternatives taking into account the full range of credible evidence. But too often it is devalued and represents little more than sensitivities around some conventional strategic plan. Scenarios, properly used, can assist in securing a safe and stable future, but only if applied with brutal honesty in exploring extremes and not just a predetermined path.
- The six scenarios proposed by the NGFS do not conform to good scenario-planning methodology. The four key scenarios are based on one set of assumptions and a pre-determined path: Paris compliant, unsustainable economic growth, a reliance on technologies not yet proven or deployed at scale, overshoot of the temperature target, a big continuing role for gas, and with a blind eye turned to key dynamics of the climate system.
- Scientists and analysts consider 4°C of warming to be an existential threat, incompatible with the maintenance of human civilisation, and 3°C to be catastrophic, perhaps leading to outright chaos in the relations between nations. Applying stress tests to such circumstances is problematic. Even at 3°C, the impacts may be so great as to be potentially infinite and unquantifiable, making model-based scenario testing largely irrelevant. It is unlikely that the banking system could survive such levels of warming.
- Markets crave stability, but the world is entering an era of instability and uncertainty driven, inter alia, by climate-related financial risks, preventing the generation of reliable prices. This makes the current approaches to managing these risks not fit for purpose.
- Sensible risk management, especially for highly uncertain events, demands a precautionary approach, which should be applied to climate-related financial risks. Disclosure of risks is not enough; time is short and mitigating those risks should be the key focus for regulators and policymakers.
- If the financial system is to survive and prosper, such precautionary action must ensure temperature outcomes do not trigger further tipping points or a Hothouse Earth cascade, and return the system to the stable climate conditions under which human civilisation flourished. This means emergency action to keep the temperature increase to a minimum, coupled with drawdown of current atmospheric carbon concentrations.
- The NGFS and TCFD recommendations, along with regulatory guidance in general, exert great influence over financial and corporate market responses to climate risk. We urge that these recommendations and guidance be reframed to encompass emergency precautionary action appropriate to the threats outlined in this paper.

INTRODUCTION

After thirty years of inaction, with global carbon emissions continuing to rise in line with worst-case scenarios and climate-related disasters intensifying around the globe, climate change is finally beginning to be taken seriously by the business and financial communities.

The investment and insurance communities in particular are emerging as leaders in pursuing climate action, given the mounting social and economic cost of climate impacts. Financial market regulators have been instrumental in accelerating this process, with their independent mandates and fiduciary responsibilities to maintain stability in financial markets. The establishment in 2015 by the Financial Stability Board (FSB) of the Task Force on Climate-related Financial Disclosures (TCFD) was a major step forward in focusing business attention on the importance of addressing climate change. The initial 2017 TCFD recommendations on climate risk disclosure[1] are being adopted widely, particularly the encouragement of scenario planning as a means of better understanding the full range of climate risks and uncertainties.

Other initiatives have spun off from this work, notably the 2017 formation by eight central banks of the Network for the Greening of the Financial System (NGFS). The NGFS has moved rapidly to propose a standardised scenario-planning approach, so as to provide comparability on climate risk assessment across the banking sector and, potentially, the wider business communities. The NGFS *Climate scenarios for central banks and supervisors* were first published in 2020 and updated in June 2021.[2]

The Australian financial regulators, the Australian Prudential Regulatory Authority (APRA), the Australian Securities and Investment Commission (ASIC) and the Reserve Bank of Australia (RBA) have been heavily involved in these initiatives, coordinating local activities via the Council for Financial Regulators (CFR).

In April 2021, APRA released a draft *Prudential practice guide*[3] on climate change financial risks for APRA-regulated institutions, for stakeholder feedback by 31 July 2021. This draws heavily on the TCFD recommendations on climate-related financial risk disclosure (CFRD), including the use of scenario analysis as suggested by both the TCFD and NGFS. APRA recommends consideration of scenarios including one which, in the absence of mitigating action and policies, exceeds 4°C by 2100 relative to pre-industrial conditions, as well as a 2°C outcome more or less consistent with the 2015 *Paris Agreement.*

In May 2021 APRA, on behalf of the CFR, issued a request for the provision of physical climate risk data to be used in a climate vulnerability assessment project with major Australian authorised deposit-taking institutions. This called for detailed information, assessed against two of the NGFS scenarios, one of which, a "Hothouse world", would exceed 3°C.[4]

Internationally, the Bank of England (BoE) is about to stress test its financial system, including one scenario in which the climate target of 2°C is exceeded.[5] The European Central Bank (ECB) is currently conducting an economy-wide climate stress test, encompassing approximately four million companies and 2000 banks for a period of 30 years into the future. Initial indications suggested that climate change "represents a major source of systemic risk, particularly for banks with portfolios concentrated in certain economic sectors and, even more importantly, in specific geographical areas".[6] Again, the proposed stress test relies heavily on the NGFS scenario analysis.

Given the weight now being attached to this type of stress testing, and its potential importance in directing the global response to climate change, this report seeks answers to several critical questions:

- How should climate stress testing be structured in the circumstances now posed by the extent and accelerating pace of climate change?
- Does the theoretical emphasis on scenarios, and average global temperature increase, obscure the hard-nosed practical implications of actual climate risk and uncertainty?
- Do the scenarios proposed by the NGFS articulate the full range of risks and uncertainties posed by climate change? In particular, does primary reliance on modelling, quantification and probabilistic analysis cloud this assessment, with the most-damaging, plausible, high-end possibilities being ignored in favour of the middle-of-the-distribution outcomes?
- What is an appropriate risk-management framework for assessing the consequences of higher levels of average global warming, for example in excess of 3°C, given that impacts have been variously described as "catastrophic", "outright social chaos", and potentially "existential for human civilisation"?
- At what point should the probabilistic quantification of climate risk give way to precautionary action to manage climate uncertainties which cannot, with present knowledge, be quantified? A case in point is the potential triggering of non-linear processes and cascades from system-level tipping points.

The answers are important not just for Australian regulators, but in a global context given the weight being attached to the NGFS, BoE and ECB initiatives in international policy deliberations, and in individual investor and business decisions.

1 TCFD 2017, Recommendations of the task force on climate-related financial risk disclosure, Task Force on Climate-Related Financial Disclosures.

2 NGFS 2021, Climate scenarios for central banks and supervisors, Network for Greening the Financial System.

3 APRA, 2021, Prudential practice guide: Draft CPG 229 climate change financial risks, Australian Prudential Regulation Authority, Sydney.

4 Ziffer, D 2021, 'Financial regulator APRA to stress-test banks on climate change, to examine what would happen in a 3-degrees-hotter world', ABC News, 29 May; APRA 2021, Request for information (RFI) PRQ0002982for the provision of physical climate risk data, Australian Prudential Regulation Authority, Sydney.

5 Bank of England 2019, Discussion paper: The 2021 biennial exploratory scenario on the financial risks from climate change, Financial Policy Committee/Prudential Regulation Committee, Bank of England, London.

6 de Guindos, L 2021, 'The ECB's economy-wide climate stress test', Green Central Banking, 18 March.

CLIMATE LESSONS FROM THE GLOBAL FINANCIAL CRISIS

In considering the response of financial markets to the threat of climate change, many lessons may be learnt from the 2008 Global Financial Crisis (GFC).

Scenarios, modelling and stress testing, by banks and regulators alike, failed to foresee the GFC and the consequences for the banking system, investors and business more broadly.

Former BoE Governor, Mervyn King, and his economist colleague, John Kay, have concluded that the GFC "bought home the intellectual failures of optimising models to capture the disruptive behaviour that results from confronting an unknowable future", because the models used by regulators and financial institutions, derived from academic research in finance, "not only failed to prevent the 2007-8 crisis but actively contributed to it". These models assumed "a stable and unchanging structure of the economy and could not cope with unique events that derived from the essential non-stationarity of a market economy".[7]

The story of the GFC, say Kay and King, is that risks were placed not with those who understood them, but with those that did not:

> The risk models used by Goldman Sachs and other financial firms were incapable of coping with the stress in markets seen in 2007 and more starkly in 2008. The models used by economists in central banks and elsewhere to make forecasts of the economy also failed to predict or explain these events. The inability of experts to anticipate the crisis was not simply the result of incompetence, or wilful blindness, but reflected much deeper problems in understanding risk and uncertainty.[8]

Put another way by Lord Robert Skidelsky in discussing the origins of the GFC:

> The key theoretical point in the transition to a debt-fuelled economy was the re-definition of uncertainty as risk. This was the main achievement of mathematical economics. Whereas guarding against uncertainty had traditionally been a moral issue, hedging against risk is purely a technical question.[9]

At the London School of Economics in 2008, Queen Elizabeth questioned: "Why did no one foresee the timing, extent and severity of the Global Financial Crisis?" The British Academy answered a year later that "a psychology of denial" gripped the financial and corporate world, and that it was "the failure of the collective imagination of many bright people… to understand the risks to the system as a whole".[10]

The harsh reality is that these critiques may also be applied to the way climate change risk and uncertainty is being treated by regulators and climate policy makers, and by the Intergovernmental Panel on Climate Change (IPCC).

IPCC reports are overly-cautious, erring on the side of "least drama", and downplaying the more extreme and more damaging outcomes.[11] Whilst some scientific caution is understandable, IPCC assessment reports, in exhibiting scholarly reticence, do bear a large responsibility for underplaying climate risk.[12] Models are privileged over other forms of knowledge, such as expert elicitations and Earth's paleoclimate history.

The question today is whether similar systemic failings, observed during the GFC and in international climate policymaking fora, will also plague attempts to adequately stress test the global and Australian financial systems against the realities of climate change impact, particularly at higher levels of warming above 3°C.

7 Kay, J & King, M 2020, Radical uncertainty: Decision-making for an unknowable future, The Bridge Street Press, London.

8 Kay, J & King, M 2020, op. cit.

9 Skidelsky, R 2008, 'Morals and the meltdown', Project Syndicate, 20 November.

10 Stewart, H 2009, 'This is how we let the credit crunch happen, Ma'am …', The Guardian, 26 July.

11 Brysse, K et al. 2013, 'Climate change prediction: Erring on the side of least drama?', Global Environmental Change, vol. 23, pp. 327-337.

12 Spratt, D & Dunlop, I 2018, What lies beneath: The understatement of existential climate risk, Breakthrough National Centre for Climate Restoration, Melbourne.

FINANCIAL MODELS NOT ONLY FAILED TO PREVENT THE 2007-8 CRISIS BUT ACTIVELY CONTRIBUTED TO IT. THE INABILITY TO ANTICIPATE THE CRISIS WAS NOT SIMPLY THE RESULT OF INCOMPETENCE, OR WILFUL BLINDNESS, BUT REFLECTED MUCH DEEPER PROBLEMS IN UNDERSTANDING RISK AND UNCERTAINTY.

FINANCIAL STRESS TESTS

A stress test is an analysis of the capacity of a process or institution/s to respond to a shock. In this context, it is a simulation, based on modelling, of the impacts of plausible adverse scenarios on the resilience of financial institutions. The stress-testing of climate-related financial risks (CRFR) has been strongly advocated by the TCFD and the NGFS. CRFR are endogenous, systemic in nature and unique in their far-reaching impact, unforeseeable nature and irreversibility.

In the banking sector, stress tests are "forward-looking exercises that aim to evaluate the impact of severe but plausible adverse scenarios on the resilience of financial institutions", first used in a systematic way by IMF and World Bank in 1999, and now common practice amongst regulators.[13] Stress tests may micro-focus on individual banks, or macro-focus on the financial system as a whole. The latter is a more complex exercise, accounting for linkages between financial players, compounding effects and assessing system-wide responses to unpleasant shocks.

A stress test is a complex "what if" exercise, a simulation based on scenario modelling. Stress factors can be drawn from historical events or hypothetically created. Stress tests are subject to limitations, including the validity of their methodology, risk management and assumptions, the capacity to construct efficacious scenarios, the capacity of models to incorporate contagion effects, and the quality and availability of data. It is a hypothetical exercise and a stress test "should not be expected to accurately predict the impact of a specific, forthcoming crisis".[14]

More than anything else, the worth of a stress test depends on the value of the scenario underlying it. If the scenario analysis cannot capture the full range of likely effects deriving from the shock, or anticipate the nature of shocks, then the stress test will be of little value. This is a key issue for higher warming scenarios, in which the consequences, as discussed in this report, are global in impact, potentially non-linear in character and hence difficult to project, subject to high levels of uncertainty, and with wide second-order impacts such that quantification may be impossible.

Stress testing, along with disclosure and transparency, is considered an important element in reducing the information gap as banks and supervisory authorities search for means to respond to CRFR. But the key implication of the current climate-related stress-test narrative, say researchers, is that "while action is needed now, it may not be possible to do so since there is insufficient 'intellectual capacity' to understand the nature of CRFR and how policy interventions may affect their development".[15]

The Financial Stability Institute says that stress tests are most effective "when their design is fully aligned with the policy objectives associated with them. It is crucially important that authorities make an early decision about why they would like to run a stress test, and how they plan to use the results."[16]

13 Baudino, P et al. 2018, FSI Insights on policy implementation No 12: Stress-testing banks – a comparative analysis, Financial Stability Institute, Bank for International Settlements, Basel.

14 Baudino, P et al. 2018, op. cit.

15 Chenet, H, et al. 2021, 'Finance, climate-change and radical uncertainty: Towards a precautionary approach to financial policy', Ecological Economics, vol. 183, art. 106957.

16 Baudino, P et al. 2018, op. cit.

UNDERSTANDING SCENARIOS

As the complexity of the issues facing business, government and society mount, scenario planning has become an increasingly popular technique. It is rare to find a policy or economic report these days which does not claim to incorporate some form of scenario analysis, as witnessed in the deliberations of the TCFD and NGFS.

The technique, properly used, is powerful, but the term has become somewhat devalued; much of the work today that purports to be scenario analysis represents little more than sensitivities around some conventional strategic plan. Often that is the case with climate change policy, both in Australia and globally.

Scenario planning had its genesis in the early days of the Cold War when futurist Herman Kahn and colleagues at the Rand Corporation developed the technique to "think the unthinkable" in regard to possible outcomes of nuclear deterrence. It was subsequently adopted by business, particularly by Royal Dutch Shell, to sensitize and broaden mindsets to critical global developments, especially the unexpected, and to adjust corporate strategy accordingly.

Scenarios are coherent, credible stories about alternative futures. They are created around a synthesis of multiple, wide-ranging perspectives on a particular problem, rather than detailed development of a single viewpoint. Scenario planning does not forecast, predict or express preferences for the future; rather the story-telling paints internally-consistent pictures of alternative worlds, which might emerge given certain assumptions, that are credible in the light of both known and lesser known factors.

Strategy is then assessed against each possible future. Some elements of strategy will be common under all scenarios, but others will differ markedly; the final strategic choice is made in the light of the organization's preferences, but with a better understanding of the possible risks the future might hold whichever world actually eventuates. Contingency plans can then be developed to manage those risks.

One of the key tasks in initiating a scenario planning exercise is to identify the "Official future", the future as it is supposed to be, and upon which prevailing strategy is based. Inevitably there is a large amount of "political" capital tied up in that view, often a result of group-think generated by dominant individuals, or ideology, which nobody is prepared to contest, or by business or political models which have stood the test of time but which may be ill-equipped for a radically-different future as it might unfold.

A great advantage of the technique, given that it is setting out to explore but not predict the future, is that, if done properly in a non-threatening manner, it allows for constructive discussion on alternatives taking into account the full range of credible evidence. In particular, there must be a preparedness to "think the unthinkable", and explore extreme but credible scenarios beyond conventional wisdom. Once those perspectives are available and understood by the key players, a re-assessment of the "Official future" is often inevitable and undertaken proactively.

And so it is with climate change policy. In Australia, the "Official future" for the last two decades has been, and remains, climate denial and delay. Views have become incredibly polarized, based primarily on the dominance of short-term thinking in business, political expediency and blinkered ideology. The science is ignored and key advice sidelined. Policy, such as it is in Australia, reflects a desire to stay within our comfort zone, using predatory delay[17] to prolong the life of a high-carbon economy as long as possible for short-term financial gain, irrespective of the damage it may do to the community, and to the proponents themselves. So Australia's wholly inadequate emission reductions, of 26-28% by 2030, are seen to be a "challenging" task. "Unthinkable" futures, for example that those targets might have to be much stronger because the world may heat to 1.5°C by 2030 as the latest science suggests, are not entertained.

The global "Official future" is changing rapidly as climate impacts and associated costs escalate. Leaders and institutions such as the International Energy Agency (IEA), the World Economic Forum, the World Bank, the International Monetary Fund (IMF), Academies of Science and the United Nations — along with governments in the UK, Ireland, Canada, France and Catalonia, and cities such as New York, London and Sydney, under pressure from their communities — are calling for emergency action if catastrophic climate outcomes are to be avoided. The implication is that radically different steps must be taken if the world is to seriously address the issue, particularly to maintain global financial stability.

Scenarios, properly used, can assist in securing this future, but only if applied with brutal honesty in exploring extremes.

17 Steffen, A 2016, 'Predatory delay and the rights of future generations', Medium, 30 April.

CORPORATE RISKS AT 3-4°C

APRA's draft *Prudential practice guide* on climate change financial risks, released in April 2021, proposes "prudent practices in relation to climate change financial risk management" for Australian companies.

The guidance follows the TCFD initiative and overseas practice in emphasising monitoring and disclosure as key corporate responses to climate risks. The APRA guide "does not impose new requirements in relation to climate risks", nor does it "seek to determine an institution's individual investment, lending or underwriting decisions, but does aim to ensure that these decisions are well-informed". Scenario analysis, with both a short- and long-term time horizon, is considered "a useful tool for informing the risk identification process".[18]

APRA suggests two future temperature-rise scenarios against which companies might calibrate themselves:

- "Global average temperatures continuing to rise in the absence of mitigating actions and policies (for example, temperature increases in excess of 4°C by 2100), leading to greater physical climate risks"; and
- "Global average temperatures rising by 2°C or less consistent with the *Paris Agreement,* reducing the magnitude of long-term physical risks."

This implies some naivety, or ignorance, about the impacts of 4°C of warming.

Scientists are clear that 4°C is beyond the adaptive capacity of most economies. Prof. Kevin Anderson says that a 4°C future "is incompatible with an organised global community, is likely to be beyond 'adaptation', is devastating to the majority of ecosystems and has a high probability of not being stable".[19] Prof. Johan Rockström says that at 4°C: "It's difficult to see how we could accommodate eight billion people or maybe even half of that… There will be a rich minority of people who survive with modern lifestyles, no doubt, but it will be a turbulent, conflict-ridden world."[20] Eight years ago, the World Bank reported that "there is no certainty that adaptation to a 4°C world is possible".[21]

Amongst other impacts, 4°C would in the long run melt both polar ice caps, with a sea-level rise of around 70 metres. Even 3°C would be catastrophic and make some nations, and regions, unlivable (see *Snapshot of a hotter world* on page 18).

Anderson says that 2°C of warming represents a threshold between "dangerous" and "extremely dangerous" climate change.[22]

Prof. Andy Pitman, Director of the ARC Centre of Excellence for Climate Extremes in Australia notes that global mean warming is badly understood. As a general rule of thumb, global average warming of 4°C (covering land and ocean) is consistent with 6°C over land, and 8°C in the average warming over mid-latitude land. That risks 10°C in the summer average, or perhaps 12°C in heatwaves. Western Sydney has already reached 48°C. If you add 12°C to the 48°C you get summer heatwaves of 60°C.[23] Bank customers would be dead on the streets.

As mentioned, in May 2021 APRA called for proposals to provide physical climate risk data based on modelling, for a climate vulnerability assessment, built around two NGFS scenarios, one of which, Hothouse World, exceeds 3°C. The data is to encompass "acute and chronic physical risks expected to include a combination of some or all of the following risk types at each asset location: extreme heat, rainfall and wind; flooding/inundation, soil subsidence and coastal inundation, fire and bushfire; and storms".

This demands a granularity in climate models that may not be presently available, and potentially a large allocation of available research capacity to identify climate impacts on individual private assets. In itself, it would provide a narrow picture of climate-warming impacts which does not take into account second-order risks, or the impacts of climate disruption beyond Australia on the nation and its economy.

But the critical question is whether the regulator, in providing such guidance and information requests for 3–4°C warming scenarios, creates a complacency amongst regulated companies that they could, in theory, be resilient to such levels of warming. This would be dangerously misleading. Given the reactive manner in which many companies have adopted standard scenarios from the IPCC or the IEA in implementing TCFD recommendations, this is a major concern.

18 APRA, 2021, Prudential practice guide: Draft CPG 229 climate change financial risks, Australian Prudential Regulation Authority, Sydney.

19 Roberts, D 2011, 'The brutal logic of climate change', Grist, 6 December.

20 Vince, G 2019, 'The heat is on over the climate crisis. Only radical measures will work', The Guardian, 19 May.

21 World Bank 2012, Turn down the heat: Why a 4°C warmer world must be avoided, World Bank, Washington DC.

22 Anderson, K & Bows, A 2015, 'Beyond "dangerous" climate change: emission scenarios for a new world', Phil. Trans. R. Soc. A, vol. 369, pp. 20-43.

23 Pitman, A 2021, pers. comm, 6 June 2021.

RISKY BUSINESS: ASSESSING CLIMATE CONSEQUENCES

> Predictive models are the lifeblood of climate science, and the foundation upon which political responses to the climate and ecological crisis are often based. But their ability to predict such large-scale disruptive events is severely limited.
>
> — Wolfgang Knorr and Will Steffen[24]

A risk is something bad that might happen. A risk assessment asks the questions: "What might happen?", "How bad would that be?" and "How likely is that?" The answers to these questions can inform decisions about how to respond.

In constructing scenarios for financial stress tests, the key starting point is the form of risk management to be employed. What risk of failure is acceptable? What focus is to be given to the high-end, "fat tail" possibilities? How is uncertainty to be treated? And so on.

Key issues include the following.

System complexity and uncertainty

The science of climate change is inherently complex because it describes the dynamics of a multi-dimensional, non-linear system, involving many subsystems and networks of adverse cascade effects.[25] Some responses to increasing levels of greenhouse gases are relatively linear and able to be projected well by climate models, such as near-term increases in temperature, increasing levels of atmospheric water vapour, more intense wind events, longer heat waves and so on. In this arena, climate models are very valuable.

But other responses are non-linear, characterised by sudden changes, rather than smooth progress, which take the system from one discrete state to another, possibly with system cascades. Factors contributing to this non-linearity include the existence of tipping points — polar ice sheets, for example — where a threshold exists beyond which large, system-level change will be initiated, and positive feedbacks or self-reinforcing loops driving further change. In a period of rapid warming, most major tipping points once crossed are irreversible on human time frames.

We live in a world of *radical uncertainty* in which "our understanding of the present is imperfect, our understanding of the future even more limited, and in which no one person or organisation can hold the range of information required to arrive at the 'best explanation'".[26] Climate models have not so far been able to realistically incorporate all the system interactions, such as those involving terrestrial carbon stores, large-scale ocean and atmospheric circulation systems, and polar ice sheets.

In complex systems, small changes can sometimes lead to large divergences in future state. The risks of climate change to human interests will depend not only on the direct impacts of changes in the physical climate, but also on the response of complex human systems such as the global economy, food markets, and the system of international security.[27]

CRFRs cascade along complex and uncertain paths: from the direct physical drivers of warming — the human emission of greenhouse gases — through to social and economic consequences. *The green swan: Central banking and financial stability in the age of climate change* report, released in 2020 by the Bank for International Settlements (BIS), concludes that:

> Integrating climate-related risk analysis into financial stability monitoring is particularly challenging because of the radical uncertainty associated with a physical, social and economic phenomenon that is constantly changing and involves complex dynamics and chain reactions. Traditional backward-looking risk assessments and existing climate-economic models cannot anticipate accurately enough the form that climate-related risks will take. These include what we call "green swan" risks: potentially extremely financially disruptive events that could be behind the next systemic financial crisis.[28]

Probabilistic analysis limitations

Climate warming above 3°C poses an existential risk to contemporary human societies (see *Too hot to handle: An existential risk at 3°C?* on page 14).

Existential risk and unpredictable, non-linear processes mean climate change consequences cannot be adequately expressed by probabilistic analyses which reduce complexity and high levels of uncertainty to models, numerical expressions and formulae. Corporate and state climate plans and scenarios lack appropriate non-probabilistic risk-management approaches to both the physical and social risks, and exhibit an inadequate understanding of such high-end possibilities.

Researchers emphasise that "the envelope of possibilities", that is, the full range of possibilities for which one must be prepared, is often more important than the most likely probabilistic future outcome, especially when the range of outcomes includes those that are particularly severe. They conclude that the "application of scientific rather than risk-based norms in communicating climate change uncertainty has also made it easier for policymakers and other actors to downplay relevant future climate risks".[29]

24 Knorr, W & Steffen, W 2020, 'We climate scientists won't know exactly how the crisis will unfold until it's too late', The Conversation, 12 March.

25 Chenet, H, et al. 2021, op cit..

26 Kay, J & King, M 2020, op. cit.

27 King, D et al. 2016, Climate change: A risk assessment, Centre for Science and Policy, University of Cambridge.

28 Bolton, P et al. 2020, The green swan: Central banking and financial stability in the age of climate change, Bank for International Settlements, Basel.

29 Weaver, C et al. 2017, 'Reframing climate change assessments around risk: recommendations for the US National Climate Assessment', Environmental Research Letters, vol. 12, art. 080201.

Acceptable levels of risk

Based on the work of the IPCC, climate policy-making institutions such as the Conference of the Parties (COP) under the United Nations Framework Convention on Climate Change (UNFCCC), and most national governments, accept as reasonable a 33% — or even a 50% — risk of failure, even when that failure equates with planetary-level systems disruption.

Examples of this are the risks of a one-in-two or one-in-three chance of failure used in "carbon budgets", which justify continuing high levels of emissions for decades as being consistent with the *Paris Agreement* goals. Yet people do not accept even a 1% risk of failure when they cross a bridge or get into a lift, so what is the ethical basis for policymakers and regulators accepting large risks of failure when it comes to the planet?[30]

It is important that regulators do not fall into the trap of accepting risks associated with adverse scenarios that they would not accept in their own lives.

Thinking the unthinkable

Successful risk management requires thinking "outside the box", rather than in silos, to avoid a failure of imagination, but this is a skill rarely found at the senior levels of government and global corporations. A "failure of imagination" was, for example, identified as one of the reasons for the breakdown in US intelligence around the 9/11 attacks in 2001, and for banks and regulators not anticipating the 2008 GFC.

A 2016 report, *Thinking the unthinkable*, based on interviews with top leaders around the world, found that: "A proliferation of 'unthinkable' events… has revealed a new fragility at the highest levels of corporate and public service leaderships. Their ability to spot, identify and handle unexpected, non-normative events is… perilously inadequate at critical moments."[31]

The report identified a deep reluctance, or what might be called "executive myopia" amongst top leaders in both the public and private sectors, to see and contemplate even the possibility that "unthinkables" might happen, let alone how to handle them. The rate and scale of change is much faster than most are even prepared to concede or respond to.

At the highest board and senior management levels, executives and their public service equivalents confessed to often being overwhelmed. Time is at such a premium that the pressing need to think, reflect and contemplate in the ways required by the new "unthinkables" is largely marginalised.

Often blind eyes were turned, either because of a lack of will to believe the signs, or an active preference to deny and then not to engage.

In regard to climate change, the Managing Director of Royal Dutch Shell, Ben van Beurden, confirmed: "Yeah, we knew. Everybody knew. And somehow we all ignored it."[32]

Diversity of research methods

It is fundamentally important that knowledge about climate impacts be drawn from a diverse range of sources and methods, and that research does not become too dependent on one set of processes, such as models, for example.

There is a consistent pattern in the IPCC and the research community of presenting detailed, quantified (numerical) modelling results, but then briefly noting more severe possibilities — such as feedbacks that the models do not account for — in a descriptive, non-quantified form. Sea-level rise, polar ice sheets and some carbon-cycle feedbacks are three examples. Because policymakers and the media are often drawn to headline numbers, this approach results in less attention being given to the most devastating, high-end and difficult-to-quantify outcomes.

Consensus around numerical results can result in an understatement of the risks. Oppenheimer et al. point to the problem:

> The emphasis on consensus in IPCC reports has put the spotlight on expected outcomes, which then become anchored via numerical estimates in the minds of policymakers… it is now equally important that policymakers understand the more extreme possibilities that consensus may exclude or downplay… given the anchoring that inevitably occurs around numerical values, the basis for quantitative uncertainty estimates provided must be broadened to give observational, paleoclimatic, or theoretical evidence of poorly understood phenomena comparable weight with evidence from numerical modeling… One possible improvement would be for the IPCC to fully include judgments from expert elicitations.[33]

This cannot be overemphasised.

30 Spratt, D & Dunlop, I 2021, Briefing note: Carbon budgets for 1.5 & 2°C, Breakthrough National Centre for Climate Restoration, Melbourne.

31 Gowing, N & Langdon, C 2016, Thinking the unthinkable: A new imperative for leadership in the digital age, Chartered Institute of Management Accountants, London.

32 van Beurden, B 2020,'The reason fossil fuel companies are finally reckoning with climate change', Time, 16 January.

33 Oppenheimer, M et al. 2007, 'The limits of consensus', Science, vol. 317, pp. 1505-1506.

IN COMPLEX SYSTEMS, SMALL CHANGES CAN SOMETIMES LEAD TO LARGE DIVERGENCES. CLIMATE CHANGE RISKS DEPEND NOT ONLY ON DIRECT PHYSICAL IMPACTS, BUT ALSO THE RESPONSE OF COMPLEX HUMAN SYSTEMS SUCH AS THE GLOBAL ECONOMY, FOOD MARKETS AND THE SYSTEM OF INTERNATIONAL SECURITY.

TOO HOT TO HANDLE: AN EXISTENTIAL RISK AT 3°C?

Human-induced climate change is an existential risk to human civilisation — where existential risk is understood as an adverse outcome that will either annihilate intelligent life or permanently and drastically curtail its potential.

Hosting a climate and security panel as part of US President Joe Biden's Leaders Summit on Climate on 22 April 2021, US Secretary of Defence Lloyd J. Austin III opened his remarks with these words: "Today, no nation can find lasting security without addressing the climate crisis. We face all kinds of threats in our line of work, but few of them truly deserve to be called existential. The climate crisis does."[34]

There is an unacceptable risk that the impacts of 3°C of warming will be existential for many nations, regions and societies.

In 2017, one of the first research papers to focus explicitly on existential climate risks proposed that "mitigation goals be set in terms of climate risk category instead of a temperature threshold", and established a "dangerous" risk category of warming greater than 1.5°C, and a "catastrophic" category for warming of 3°C or more.[35] The study focuses on the world's poorest three billion people:

> Climate risks can vary markedly depending on the socioeconomic status and culture of the population, and so we must take up the question of "dangerous to whom?"... the poorest three billion people living mostly in tropical rural areas, are still relying on 18th-century technologies for meeting basic needs such as cooking and heating. Their contribution to carbon dioxide pollution is roughly 5% compared with the 50% contribution by the wealthiest one billion. This bottom three billion population comprises mostly subsistence farmers, whose livelihood will be severely impacted, if not destroyed, with a one- to five-year megadrought, heat waves, or heavy floods; for those among the bottom three billion of the world's population who are living in coastal areas, a 1- to 2-metre rise in sea level (likely with a warming in excess of 3°C) poses existential threat if they do not relocate or migrate.[36]

Prof. Hans Joachim Schellnhuber, Director Emeritus of the Potsdam Institute for Climate Impact Research, says that: "If we go into a runaway climate effect, the damage may be between €100 trillion and the loss of civilisation … If we don't solve the climate crisis, we can forget about the rest."[37]

A 2017 survey of global catastrophic risks by the Global Challenges Foundation (GCF) found that: "In high-end [climate] scenarios, the scale of destruction is beyond our capacity to model, with a high likelihood of human civilisation coming to an end."[38] The GCF says that despite scientific evidence that risks associated with tipping points "increase disproportionately as temperature increases from 1°C to 2°C, and become high above 3°C", political negotiations have consistently disregarded the high-end scenarios that could lead to abrupt or irreversible climate change. It concludes that "the world is currently completely unprepared to envisage, and even less deal with, the consequences of catastrophic climate change".[39]

In 2019 scientists offered a climate emergency formula: generally, risk is considered to be the potential damage multiplied by the probability, but in this equation, another element is added, called urgency.[40] This is the relationship between:

- the reaction time "τ" (how long it takes to solve a problem); and
- the intervention time "T" (the time you actually have, before it is "too late").

Think of the Titanic: "If reaction time is longer than the intervention time left ($\tau / T > 1$), we have lost control."[41] They suggest this is already a non-trivial possibility with the climate system at the current 1.2°C warming.

34 Austin, LJ 2020, 'Secretary Austin remarks at Climate Change Summit', US Department of Defence, Washington DC, 22 April.

35 Xu, Y & Ramanathan, V 2017, 'Well below 2°C: Mitigation strategies for avoiding dangerous to catastrophic climate changes', Proc. Natl. Acad. Sci., vol. 114, pp. 10315-10323.

36 Xu, Y & Ramanathan, V 2017, op. cit.

37 Roberts, J 2019, '"I would like people to panic" – Top scientist unveils equation showing world in climate emergency', Horizon, 24 September.

38 Global Challenges Foundation 2017, Global catastrophic risks 2017, Global Challenges Foundation, Stockholm.

39 Global Challenges Foundation 2017, op. cit.

40 Lenton, TM et al, 2020, 'Climate tipping points — too risky to bet against', Nature, vol. 575, pp. 592-595.

41 Lenton, TM et al, 2020, op. cit.

THE SCIENCE OF 3°C: A CASCADE OF SYSTEM-LEVEL DISRUPTIONS

The global average warming trend is now above 1.2°C, compared to the late nineteenth century. Three of the last five years have been greater than 1.2°C, and warming accelerated to ~0.25°C for the most recent 2011-20 decade, compared to the average recent decadal rate of warming prior to 2010 of less than 0.2°C.[42]

Many research papers and models project warming to reach 1.5°C around 2030, or sooner, a decade ahead of IPCC 2018 Special Report projections.[43] A comparison of results from the latest generation of climate models suggests 1.5°C may be only five-to-seven years away (see table).[44] Rising emissions, declining aerosols (air pollution) and natural climate cycles will contribute to faster warming,[45] as will greater stratification of the ocean.[46]

Warming scenarios

	Low	Central	High
1.5°C	2028	2027	2026
2°C	2060	2045	2039
3°C	n/a	2092	2059
4°C	n/a	n/a	2077
5°C	n/a	n/a	2094

Climate model projections from Scenario Model Intercomparison Project of CMIP6

Source: Tebaldi et l. 2021. Earth System Dynamics 12:253-293. table A7.

This research shows the median year in which warming thresholds of 1.5°C, 2°C, 3°C, 4°C and 5°C are reached for three emissions trajectories: low, central and high. The emissions path has little impact on timing of the 1.5°C threshold. 2°C will be reached before 2050 for both the high and central emission scenarios.

Under the current, high-emissions scenario, 3°C may be reached around 2060; in a middle-level emissions scenario, it is reached around 2090. And this is based on models that do not include the full range of system feedbacks.

Policies enacted as a result of the current *Paris Agreement* national emission-reduction commitments are likely to result in warming of around 3°C by 2100,[47] and perhaps 4°C or more when all system feedbacks and system non-linearities are taken into account. In 2020, the IMF reported that:

> Under unchanged policies, emissions will continue to rise relentlessly, and global temperatures could increase by an additional 2–5°C by the end of this century, reaching levels not seen in millions of years, imposing growing physical and economic damage, and increasing the risk of catastrophic outcomes across the planet.[48]

At just 1.2°C of warming, climate disruption is already dangerous, with tipping points already passed for large-scale systems including coral reefs, Arctic sea-ice[49] and West Antarctic Ice Sheet (WAIS) glaciers.[50] Parts of East Antarctica might be similarly unstable.[51] One-quarter of the Himalayan and Tien Shan ice sheets have already been lost.[52] There is debate about whether the Amazon rainforest is also close to tipping,[53] and strong evidence that before or around 1.5°C the Greenland ice sheet will reach its tipping threshold[54] (see diagram on page 16).

The *Paris Agreement* lower temperature target of 1.5°C is sufficient to drive runaway retreat of WAIS,[55] and drive the Great Barrier Reef into a death spiral.[56]

Around 2030 and with warming at 1.5°C, there is a risk of blue-water Arctic summers[57] as sea-ice extent collapses and regional warming is amplified to be three times the rate of the global average. The risk will grow substantially that Arctic carbon stores including permafrost[58] and boreal forests will suffer substantial, accelerating and unstoppable carbon losses.[59]

42 Based on NASA dataset.

43 For example: Jacob, D et al 2020, 'Climate impacts in Europe under +1.5°c global warming', Earth's Future, vol. 6, pp. 264-285; Xu, Y et al. 2018, 'Global warming will happen faster than we think', Nature, 5 December; Henley, BJ & King, AD 2017, 'Trajectories toward the 1.5°C Paris target: Modulation by the Interdecadal Pacific Oscillation', Geophysical Research Letters, vol. 44, pp. 4256-4262; Spratt,D & Dunlop, I 2020, Climate Reality Check 2020, Breakthrough National Centre for Climate Restoration.

44 Tebaldi, C et al. 2020, 'Climate model projections from the Scenario Model Intercomparison Project (ScenarioMIP) of CMIP6', Earth System Dynamics, vol. 12, pp. 253-293.

45 Xu, Y et al. 2018, op cit.

46 Berwyn, B 2020, 'New study shows a vicious circle of climate change building on thickening layers of warm ocean water', Inside Climate News, 28 September.

47 CAT 2021, 'The CAT Thermometer', Climate Action Tracker, https://climateactiontracker.org/global/cat-thermometer, accessed 21 May 2021.

48 IMF 2020, 'Mitigating climate change—growth- and distribution-friendly strategies', in World Economic Outlook Report, October, International Monetary Fund, Washington DC.

49 Dickie, G 2020, 'The Arctic is in a death spiral. How much longer will it exist?', The Guardian, 13 October.

50 Rignot, E 2014, 'Global warming: it's a point of no return in West Antarctica. What happens next?', The Guardian, 18 May.

51 Lenton, TM et al. 2020, op. cit.

52 Associated Press 2019, 'Cold War spy satellite images show Himalayan glaciers are melting fast', ABC News, 20 June; Naik, G 2015, 'Central Asia mountain range has lost a quarter of ice mass in 50 years, study says', The Wall Street Journal, 17 August.

53 Qin, Y et al. 2020, 'Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon', Nature Climate Change, vol. 11, pp 442–448.

54 Ohio State University 2020, 'Warming Greenland ice sheet passes point of no return', Science Daily, 13 August.

55 Beltran, C et al, 2020, 'Southern Ocean temperature records and ice-sheet models demonstrate rapid Antarctic ice sheet retreat under low atmospheric CO_2 during Marine Isotope Stage 31', Quaternary Science Reviews, vol. 228, 15 January.

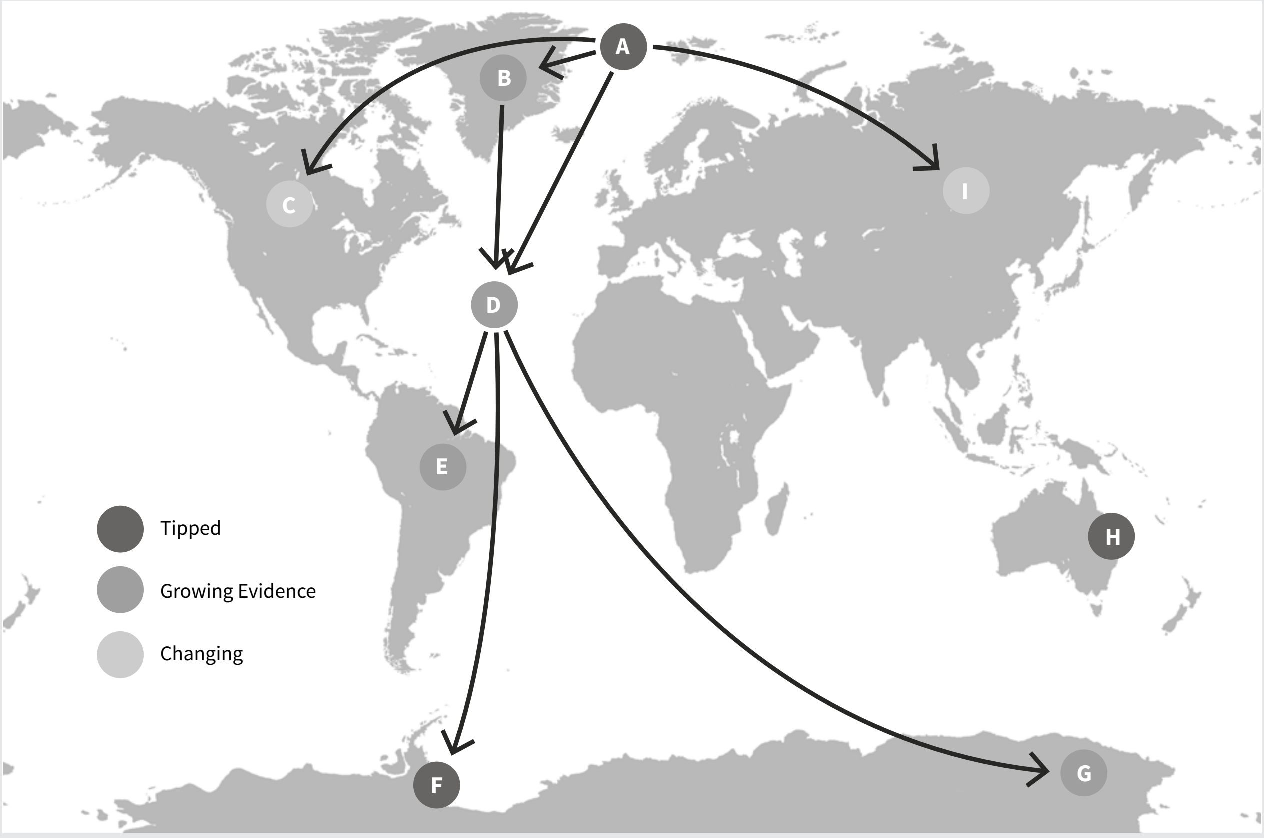
56 King, AD et al. 2017, 'Australian climate extremes at 1.5°C and 2°C of global warming', Nature Climate Change, vol. 7, pp. 412–416.

57 Monroe, R 2019, 'Loss of Arctic's reflective sea-ice will advance global warming by 25 year', Scripps Institute of Oceanography, 22 July.

58 Khurshudyan, I et al. 2020, 'Rapid Arctic meltdown in Siberia alarms scientists', Washington Post, 4 July.

59 Turetsky, MR et al. 2019, 'Permafrost collapse is accelerating carbon release', Nature, 30 April.

CLIMATE TIPPING POINTS



A Arctic sea ice
Arctic sea ice is in a death spiral: "The trend is clear: Summer ice covers half the area it did in the 1980s, and because it is thinner, its volume is down 75%" (Voosen, P 2020, *Science*, 25 August). "The Arctic is currently experiencing an abrupt climate change event… climate models underestimate this ongoing warming" (Jansen, E et al. 2020, *Nature Climate Change,* 10:714–721).

B Greenland Ice Sheet
The Greenland Ice Sheet is already close to a tipping point, previously estimated to be around 1.6°C (Robinson, A et al. 2012, *Nature Climate Change*, 2:429-432). Some researchers say it has already passed a tipping point (Arenschield, A 2020, phys.org, 13 August).

C Boreal forest
Increasing wildfires and dieback threaten the historic carbon sink of the North American boreal forests. As fires continue to increase in size, frequency and intensity, the area of young forests that experience combustion will likely increase and have a key role in shifting the boreal carbon balance (Walker, XJ et al. 2019, *Nature* 572:520–523).

D Atlantic circulation
The Atlantic Meridional Overturning Circulation (AMOC) has slowed 15% since the mid-20th century (Caesar, L et al. 2018, Nature 556:91-196), and the rate of change is accelerating. The near-term loss of summer Arctic sea ice will drive an accelerating rate of ice mass loss from Greenland, and contribute to a further slowdown of AMOC.

E Amazon rainforest
The forest systems are already oscillating to non-forest ecosystems in eastern, southern & central Amazonia (Lovejoy, TE et al. 2018, *Science Advances*, 4:eaat2340.) The Amazon is near the tipping point of switching from rainforest to savannah (Harvey, F 2020, *The Guardian*, 5 October).

F West Antarctic Ice Sheet
The Amundsen Sea sector of the West Antarctic Ice Sheet (WAIS) has most likely been destabilized and ice retreat is unstoppable for the current conditions. No further acceleration in climate change is necessary to trigger the collapse of the rest of the WAIS on decadal time scales (Rignot, E et al. 2014, *Geophys. Res. Lett.* 41:3502–3509).

G Wilkes Basin, East Antarctica
Partial deglaciation of the East Antarctic ice sheet is likely for the current level of atmospheric carbon dioxide (DeConto, RM et al. 2016, *Nature* 531:591–597). Parts of East Antarctica might be similarly unstable to West Antarctica (Lenton, TM et al. 2020, *Nature* 575:592-595).

H Coral systems
Coral systems are in a death spiral of more frequent bleaching and inadequate recovery time. Three quarters of the Great Barrier Reef has already been lost, and at 1.5°C the reef is likely to bleach two years in every three on average (King, AD et al. 2017, *Nature Climate Change*, 7:412–416), whereas recovery takes a decade or more.

I Permafrost
Some scientists consider that 1.5°C appears to be something of a "tipping point" for extensive permafrost thaw (Vaks, A. et al. 2013, *Science*, 340:183-186). The 2019 *Arctic Report Card* concludes permafrost ecosystems could already be releasing as much as 1.1 to 2.2 billion tonnes of CO_2 per year.

In the 2017 *Fourth National Climate Assessment*, US government agencies found that "positive feedbacks (self-reinforcing cycles) within the climate system have the potential to accelerate human-induced climate change and even shift the Earth's climate system, in part or in whole, into new states that are very different from those experienced in the recent past", and whilst some feedbacks and potential state shifts can be modelled and quantified, "others can be modeled or identified but not quantified and some are probably still unknown". Hence:

> While climate models incorporate important climate processes that can be well quantified, they do not include all of the processes that can contribute to feedbacks, compound extreme events, and abrupt and/or irreversible changes. For this reason, future changes outside the range projected by climate models cannot be ruled out. Moreover, the systematic tendency of climate models to underestimate temperature change during warm paleoclimates suggests that climate models are more likely to underestimate than to overestimate the amount of long-term future change.[60]

In some cases, passing one threshold will trigger further threshold events, for example, where substantial greenhouse gas releases from polar permafrost carbon stores increase warming, releasing even more permafrost carbon in a positive feedback, but also pushing other systems, such as polar ice sheets, past their threshold point. In a period of rapid warming and in the absence of geo-engineering, most major tipping points once crossed are irreversible in human time frames, principally because the climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1,000 years after emissions stop.[61]

For this reason, it is crucial that we understand as much as possible about near-term tipping points. The short-term is critical: "What we do in the next 3–4 years, I believe, will determine the future of humanity," says Sir David King, former UK Chief Scientist and advisor to four prime ministers.[62]

In 2018, scientists proposed a "Hothouse Earth" scenario in which non-linear system feedbacks and their mutual interaction cascade to drive Earth's climate to a "point of no return", whereby further warming would become self-sustaining, that is, without further human emissions.[63] They said this threshold could exist at a temperature rise as low as 2°C, possibly even in the 1.5°C–2°C range.

In a study released in June 2021 explicitly looking at the physical interactions among the Greenland and West Antarctic ice sheets, the Atlantic Meridional Overturning Circulation and the Amazon rainforest, analysts found the polar sheets are often the initiators of cascade events, with Greenland and West Antarctica at risk of passing their tipping points within the 1.5°C–2°C Paris range.[64]

In a followup in 2019 to the Hothouse paper, researchers said that:

> The evidence from tipping points alone suggests that we are in a state of planetary emergency: both the risk and urgency of the situation are acute… If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost–benefit analysis is going to help us... we might already have lost control of whether tipping happens.[65]

The evidence points to the Hothouse Earth scenario being in full swing by the time the world hits 3°C. This is a world where humanity has probably lost control of whether more tipping points are reached though most of them may well have been activated by this point. The Arctic will be a cauldron of greenhouse gases pouring from permafrost, boreal forests and possibly sub-sea methane clathrate stores.

Climate dynamics on the journey to 3°C or more of warming will be significantly shaped by non-linear processes and sudden changes, pushing many large elements of the climate system from one discrete state to another, and cascades of system-level changes.

The impacts on human society will be brutal and highly disruptive, catastrophic at the very least and perhaps existential.

60 USGCRP 2017, Climate science special report: Fourth national climate assessment, Volume I, [Wuebbles, DJ et al. (eds.)], US Global Change Research Program, Washington, DC.

61 Solomon, S et al. 2008, 'Irreversible climate change due to carbon dioxide emissions', Proc. Natl. Acad. Sci., vol. 106, 1704–1709.

62 NCE Summit 2021, 'David King', climateemergencysummit.org/speakers/david-king-speaker-profile.

63 Steffen, W et al. 2018. 'Trajectories of the Earth System in the Anthropocene', Proc. Natl. Acad. Sci., vol.115, pp. 8252-8259.

64 Wunderling, N et al. 2021, 'Interacting tipping elements increase risk of climate domino effects under global warming', Earth Syst. Dynam., vol. 12, pp. 601–619.

65 Lenton, T et al. 2019, op. cit.

SNAPSHOT OF A HOTTER WORLD

In a 3°C-warmer world, it is likely that the structures of societies will be severely tested, and some will crash. The poorest nations will suffer first and most deeply from climate change, but no region will escape.

A 2007 study by two US national security think-tanks concluded that 3°C of warming and a 0.5 metre sea-level rise would likely lead to "outright chaos" and "nuclear war is possible".[66] The researchers warned that:

> Massive nonlinear events in the global environment will give rise to massive nonlinear societal events. The specific profile of these events will vary, but very high intensity will be the norm… We could see class warfare as the wealthiest members of every society pull away from the rest of the population, undermining the morale and viability of democratic governance, worldwide… Globalization may end and rapid economic decline may begin, owing to the collapse of financial and production systems that depend on integrated worldwide systems… Alliance systems and multilateral institutions may collapse—among them the UN, as the Security Council fractures beyond compromise or repair.[67]

At 3°C, water availability will decrease sharply in the lower-latitude dry tropics and subtropics, and affect almost two billion people worldwide. Agriculture will become nonviable in the dry subtropics.[68] Southern Europe would be in permanent drought, and the Sahara will jump the Mediterranean as Europeans begin a long trek north. Water flows into the great rivers of Asia will be reduced by the loss of more than one-half, and perhaps much more, of the Himalayan ice sheet. The average drought in Central America would last 19 months longer. In northern Africa, the figure is 60 months longer: five years.[69]

Aridification will emerge over more than 30% of the world's land surface,[70] most severely in southern Africa, the southern Mediterranean, west Asia, the Middle East, rural Australia and across the south-western United States.

Most regions in the world will experience a significant drop in food production and increasing numbers of extreme weather events, including heat waves, floods and storms. Food production will be inadequate to feed the global population and food prices will skyrocket, as a consequence of a one-fifth decline in crop yields, a decline in the nutritional content of food crops, a catastrophic decline in insect populations, aridification, monsoon failure and chronic water shortages, and conditions too hot for human summer habitation in significant food-growing regions.[71]

The lower reaches of the agriculturally-important river deltas such as the Mekong, Ganges and Nile will be inundated, and significant sectors of some of the world's most populous cities — including Kolkata, Mumbai, Jakarta, Guangzhou, Tianjin, Hong Kong, Ho Chi Minh City, Shanghai, Lagos, Bangkok and Miami — inundated and/or abandoned.[72]

Deadly heat conditions will persist for more than 100 days per year in West Africa, Central America, the Middle East and South-East Asia, which together with land degradation, aridification, conflicts over land and water, and rising sea levels will contribute up to a billion people being displaced. Refugee conventions may give way to walls and blockades.[73]

3°C would be "catastrophic" for the livelihoods of the world's poorest three billion people, comprising mostly subsistence farmers, whose livelihood will be severely impacted, if not destroyed, with a one- to five-year megadrought, heat waves, or heavy floods.[74]

One of the most recent and detailed cost-benefit analyses to be published uses detailed country-specific damage calculations. It finds that losses from climate damages for the higher emission scenarios will be up to 42% of global GDP by 2100.[75]

66 Campbell, K, et al. 2007, The age of consequences: The foreign policy and national security implications of global climate change, Centre for Strategic and International Studies & Centre for New American Security, Washington DC.

67 Campbell, KM et al., 2007, op. cit.

68 Campbell, KM et al., 2007, op. cit.

69 Wallace-Wells, D 2019,'"The devastation of human life is in view": what a burning world tells us about climate change', The Guardian, 2 February.

70 "Beyond 2050, as much as 44 percent of the planet's land areas will be exposed to drying. This will lead to severe drought conditions throughout southern Europe, North America (mainly the eastern and southwestern United States and Mexico), much of southeast Asia, and most of the Amazon—affecting about 1.4 billion people. In the latitude bands between 30 degrees N and 30 degrees S the probability of multi-decadal drought will rise to 80 percent" (Xu, Y & Ramanathan, V 2017, op. cit.).

71 "Heat and droughts threaten regions that produce much of the world's food. Food prices are expected to raise 23 percent by 2030, making food markets more volatile, and under heat stress the nutritious content of food crops is declining" (Ramanathan, V et al. 2018 'Climate extremes and global health' , Foreign Affairs, 31 July 2018), "In the tropics and sub-tropics, geographic areas that include the world's hungriest people, climate change could cause crop yields to fall 10 to 20 percent or more between now and 2050" (Thornton, P 2012, Recalibrating food production in the developing world: global warming will change more than just the climate, CCAFS Policy Brief 6, CGIAR Research Program on Climate Change, Agriculture and Food Security). "Under current production systems and practices, our models indicate aggregate crop yields [in the USA] could decrease during the end of the century (2050–2100) by 8%–19% under the mildest scenario (RCP 2.6), and by 20%–48% under the most severe scenario (RCP 8.5)." (Ortiz-Bobea, A et al. 2019, 'Unpacking the climatic drivers of US agricultural yields', Environmental Research Letters, vol. 14, 064003.) "Climate models project increased aridity in the 21st century over most of Africa, southern Europe and the Middle East, most of the Americas, Australia, and Southeast Asia" (Dai, A., 2010, "Drought under global warming: a review", WIREs Climate Change, vol. 2, pp. 45-65).

72 Hanson, S et al. 2011, 'A global ranking of port cities with high exposure to climate extremes", Climatic Change, vol. 104, pp. 89–111.

73 Kang, S & Eltahir, EAB 2018, 'North China Plain threatened by deadly heatwaves due to climate change and irrigation', Nature Communications, vol. 9, 2894; In, ES et al. 2017, 'Deadly heat waves projected in the densely populated agricultural regions of South Asia', Science Advances, vol. 3, e1603322; Pal, JS & Eltahir, AB 2016, 'Future temperature in southwest Asia projected to exceed a threshold for human adaptability', Nature Climate Change, vol. 6, pp. 128–129.

74 Xu, Y & Ramanathan, V 2017, op. cit.

75 Ueckerdt, F et al. 2019, 'The economically optimal warming limit of the planet', Earth Systems Dynamics, vol. 10, pp. 741–763.

ECONOMIC ANALYSIS: MISSING LINKS AND MODEL LIMITATIONS

How can directors and regulators best assess the impact of climate warming on the companies and the markets they oversee? Is it possible to understand, even within a reasonable margin of error, the physical impacts of warming in excess of 3°C, or even 2°C? And the flow-on to social systems and the global economy? Are sea levels this century likely to rise by a single metre, or three, four or five metres? What difference would this make to the level of distressed mortgages and inundated commercial properties, major ports and coastal megacities? And on the stability of the financial system? These are not trivial questions.

Looking at the evidence already presented, the following features are significant in assessing the economic impacts at 3°C:

- By 3°C, the physical system will likely conform to the Hothouse Earth scenario of uncontrollable feedbacks and system-level cascades of disruptive events;
- In a period of rapid warming, most major tipping points once crossed are irreversible in human time frames, meaning that sea-level rises amounting to tens of metres will be in the pipeline;
- The physical impacts will undermine the capacity of many nations to survive, by way of inundation, unbearable heat, and chronic water and food insecurity, amongst many causes;
- Forced migrations, internal and cross-border conflicts may lead to the breakdown of the international order, international institutions and the globalised economy;
- The world may be characterised, as security analysts suggested more than a decade ago, as one of "outright chaos".

In these circumstances, is it even possible to quantify the economic consequences? There is the problem of analysing how first-order physical impacts drive second-order consequences for the way people live their lives: where and when will food and water insecurity become critical, how will extreme and unbearable heat drive population displacement, and how fast will rising sea-levels inundate the world's agriculturally rich alluvial flood plains? None of the answers is easily subjected to probabilistic risk assessment. Economists from the IMF and Banque de France say that:

> The uncertainty around climate change poses a challenge to the measurement of climate-related financial risks. With regard to physical risks, tipping points are very likely to exist within Earth ecosystems, but remain difficult to estimate, and exceeding them could generate multiple cascade reactions that make them particularly difficult to translate into financial metrics over uncertain time horizons. For example, while it is commonly agreed that climate change could generate mass migrations and conflicts, the probability of occurrence of such events and their translation into social, economic and then financial metrics are inherently difficult to measure with any degree of confidence.[76]

Who foresaw that an epochal drought in Syria in 2006-09 and the subsequent war would have the consequences it did: including regional destabilisation, mass migration to Europe and an impact on the Brexit decision?

Interactions between changes in the physical climate and human systems can lead to systemic risks, in which small perturbations can have large effects. The risks of climate change to human interests will depend not only on the direct impacts of changes in the physical climate, but also on the response of complex human systems such as the global economy, supply chains, food markets and the system of international security.[77]

Climate impacts are already affecting output, prices and political stability. Record-breaking fires in Russia and severe drought in China in 2010 cut the global wheat supply, and in countries most dependent on wheat exports in the Middle East and North Africa the tripling of the spot price triggered food riots and the Arab Spring uprisings. In Europe, France's central bank governor François Villeroy de Galhau points to "a slowdown in German activity with effects on the output gap and on prices… due to the (recent) low level of the Rhine."[78]

In the social and economic domains of complex systems, second-order impacts including armed conflict, state breakdown and mass migration are radically uncertain; that is, probabilities cannot meaningfully be attached to alternative futures. Climate change is a "ruin" problem of irreversible harm with a risk of total failure, meaning negative outcomes are economically unquantifiable and may become an existential threat to human civilisation.[79]

An IMF Working Paper notes a "growing agreement between economists and scientists that risk of catastrophic and irreversible disaster is rising, implying potentially infinite costs of unmitigated climate change, including, in the extreme, human extinction".[80] The 2020 BIS report concludes that: "Exceeding climate tipping points could lead to catastrophic and irreversible impacts that would make quantifying financial damages impossible."[81]

Both financial stress tests and projecting the economic consequences of climate warming primarily rely on models: physical climate models, finance system models, and climate–economy models. All these are subject to severe limitations, each in its own way. Climate models alone require a sound understanding of their limitations when applied to business climate risk assessment.[82]

76 Oman, W & Svartzman, R 2021, What justifies sustainable finance measures? Financial-economic interactions and possible implications for policymakers', CESifo Forum, vol. 22, pp. 3-11

77 King, D, et al. 2016, op cit.

78 Tett, G et al. 2021, 'Central bank action on climate is "imperative", says Banque de France', Financial Times, 3 June.

79 Chenet, H et al, 2021, op. cit.

80 Krogstrup, S & Oman, W. 2019, Macroeconomic and financial policies for climate change mitigation: A review of the literature. WP/19/185, International Monetary Fund, Washington DC.

81 Bolton, P et al. 2020, op. cit.

82 Fiedler, T et al 2021, 'Business risk and the emergence of climate analytics', Nature Climate Change, vol. 11, pp. 87-94.

Climate–economy models are notorious for their failings. Climate–economy research has focused on cost-benefit analysis (CBA), which attempts to compare the cost of mitigation with the benefit of damages avoided. However the failure to account for some likely physical changes in the climate system, the inherent incapacity to deal with damages beyond quantification, and the inadequate weighting of the benefits of mitigation policies make CBA a deeply flawed tool for policymaking.

This is especially the case with the economy–energy–climate system models, known as Integrated Assessment Models (IAMs), which reflect the social views of their architects, contain arbitrary input values and assumptions, underestimate damages and often rely on unproven technologies.[83] These models are now at the centre of the UN climate-science and policy processes, and the NGFS scenarios, but contain so many levels of inherent and irreducible uncertainties that their projections should not be used more than 20 years into the future, and even then with strict caveats as to their reliability.

Sir Nicholas Stern said of the IPCC's *Fifth Assessment Report* and its climate–economy models: "Essentially it reported on a body of literature that had systematically and grossly underestimated the risks [and costs] of unmanaged climate change."[84]

Because models are not able to effectively incorporate non-linear processes, tipping points, and cascades of interconnected system-level changes, researchers have identified a number of key "missing links" in the assessment of physical, social and economic climate risks:

- "Economic assessments of the potential future risks of climate change have been omitting or grossly underestimating many of the most serious consequences for lives and livelihoods because these risks are difficult to quantify precisely and lie outside of human experience;
- "Scientists are growing in confidence about the evidence for the largest potential impacts of climate change and the rising probability that major thresholds in the Earth's climate system will be breached as global mean surface temperature rises, particularly if warming exceeds 2°C above the pre-industrial level;
- "Many of these impacts will grow and occur concurrently across the world as global temperature climbs;"
- "Some of these impacts involve thresholds in the climate system beyond which major impacts accelerate, or become irreversible and unstoppable;
- "When a threshold is breached, it might cause one or more other thresholds to be exceeded as well, leading to a cascade of impacts;
- "Many of these impacts could exceed the capacity of human populations to adapt, and would significantly affect and disrupt the lives and livelihoods of hundreds of millions, if not billions, of people worldwide;
- "These impacts would also undermine economic growth and development, exacerbate poverty and destabilise communities;
- "Economic assessments fail to take account of the potential for large concurrent impacts across the world that would cause mass migration, displacement and conflict, with huge loss of life;
- "Economic assessments that are expressed solely in terms of effects on output (e.g. gross domestic product), or that only extrapolate from past experience, or that use inappropriate discounting, do not provide a clear indication of the potential risks to lives and livelihoods;
- "It is likely that there are additional risks that we are not yet anticipating simply because scientists have not yet detected their possibility, as we have entered a period of climate change that is unprecedented in human history; and
- "The lack of firm quantifications is not a reason to ignore these risks, and when the missing risks are taken into account, the case for strong and urgent action to reduce greenhouse gas emissions becomes even more compelling".[85]

Do we have a realistic measure of the economic costs from future climate damages? "In a word, no," is the answer from Prof. Tom Kompas, who says projections for economic damages under different global warming scenarios "are difficult to come by, save for simple, highly aggregated measures drawn from basic computational models… which can often be very misleading given their extreme and implicit tendency to average effects".[86]

Australia's 2019-2020 megafires provide a case in point, in which impacts spread across various systems: housing, infrastructure and communications, local economies, banking services, water and food security, agriculture and tourism, as well as the losses of biodiversity and ecosystems. The problem of analysis can be seen in the very wide range of estimates of the damage caused by the mega fires, from more than $A4 billion to up to $A100 billion.[87]

In 2013, Nicholas Stern concluded that: "It is vital that we treat (climate) policy analysis as that of a risk-management problem of immense proportions and discuss risks in a far more realistic way... Many scientists are telling us that our models are, grossly, underestimating the risks. In these circumstances, it is irresponsible to act as if the economic models currently dominating policy analysis represent a sensible central case."[88]

The question is whether stress tests, primarily reliant on physical and economic modelling, can provide any reasonable insight into the resilience of the financial system at high levels of climate warming.

83 Spratt, D & Armistead, A 2020, Fatal Calculations: How economics has underestimated climate damage and encouraged inaction, Breakthrough National Centre for Climate Restoration, Melbourne.

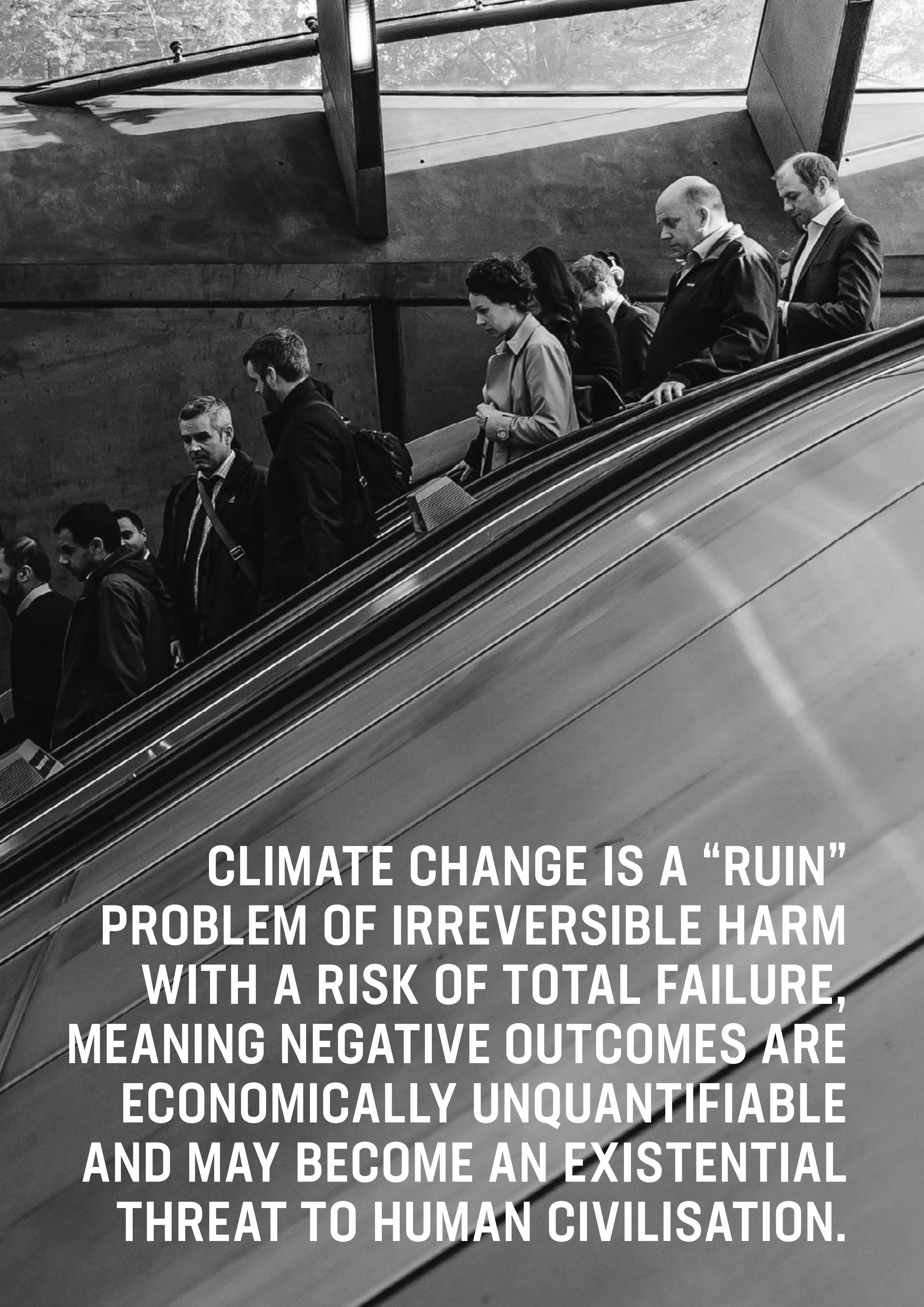
84 Stern, N 2016, 'Current climate models are grossly misleading', Nature, vol. 530, pp. 407-409.

85 DeFries, R. et al. 2019, The missing economic risks in assessments of climate change impacts. The Grantham Research Institute on Climate Change and the Environment, London, The Earth Institute at Columbia University, New York NY & The Potsdam Institute for Climate Impact Research, Potsdam.

86 Kompas, T 2020, 'What are the full economic costs to Australia from climate change?', Melbourne Sustainable Society Institute, 14 February.

87 Butler, B 2002, 'Economic impact of Australia's bushfires set to exceed $4.4bn cost of Black Saturday', The Guardian, 20 January; Read, P & Denniss, R 20202, 'With costs approaching $100 billion, the fires are Australia's costliest natural disaster'. The Conversation, 20 January.

88 Stern, N. 2013, "The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models", Journal of Economic Literature, vol. 51, pp. 838-859.



CLIMATE CHANGE IS A "RUIN" PROBLEM OF IRREVERSIBLE HARM WITH A RISK OF TOTAL FAILURE, MEANING NEGATIVE OUTCOMES ARE ECONOMICALLY UNQUANTIFIABLE AND MAY BECOME AN EXISTENTIAL THREAT TO HUMAN CIVILISATION.

FINANCIAL MARKETS: THE ERA OF INSTABILITY AND RADICAL UNCERTAINTY

Can financial markets effectively respond to such climate risks? The answer so far is not promising. The goals are hazy, and emphasis to date has been placed on reactive information flows — disclosure and reporting — and not proactive mitigation.

Recent research concludes that the TCFD approach "has not yet led to a material shift in financial flows away from unsustainable forms of financing… the world's largest investment banks have provided more than $1.9 tn of financing for the fossil fuel companies most aggressively expanding in new coal, oil and gas projects since the first launch of the TCFD in 2015".[89] As a proportion of total lending, Eurozone bank lending to carbon-intensive firms has increased since 2015.[90]

But beyond these concerns are more fundamental questions as to whether financial markets, facing systemic disruption, existential risks and radical uncertainty, can operate efficiently, or even survive, given the present regulatory environment.

Disruption

The economic models of climate change project only gradual changes, in which climates will "migrate" slowly. The models, says financial analyst Spencer Glendon, quoting Thomas C. Schelling, "probably cannot project discontinuities because nothing goes into them that will produce drastic change. There may be phenomena that could produce drastic changes, but they are not known with enough confidence to introduce into the models."[91]

Markets crave stability, and theoretically only operate "efficiently" in such conditions, but an era of growing instability is upon us. The risk intelligence company Verisk Maplecroft assesses that "there is 'no longer any realistic chance' for an orderly transition for global financial markets because political leaders will be forced to rely on 'handbrake' policy interventions to cut emissions".[92]

The global economy relies on endless layers of systems that were built within the stable climate of the past, but "investing in an environment where tomorrow doesn't look like today is very tricky," says Dickon Pinner, a senior partner at McKinsey. Pinner says that if investors don't change direction now, then governments will likely "have to pull that lever hard… and I think that would cause a lot of massive, massive disruption".[93]

Plans proposed by the Biden administration and the IEA "represent something close to the most rapid decarbonization contemporary political economy can tolerate and… may be more ambitious than will be achieved", notes author David Wallace-Wells,[94] echoing Alex Steffen's insightful essay on "The last hurrah". Steffen describes the public discourse as "beset with climate triangulation: approaches to a present and all-consuming crisis that first emphasize ambitious distant goals, then solicit modest initial steps, and then agrees to accepting those halting, insufficient actions as 'in line' with ambitious transformation. Triangulation reframes delay as responsibility."[95]

Faster paths are possible, says Wallace-Wells, "but will require considerably more disruption than has been judged broadly acceptable by global leaders even after the great climate awakening of the last couple years. And they still leave us far short of conventional temperature targets."[96]

Existential risk and uncertainty

In cases of existential risk, markets fail because they cannot adequately assess or respond to the risks. Nor can they mitigate the threat to society as a whole. This is true for weapons of mass destruction, for pandemics and for ecological collapse, and for other existential risks, where the primary risk-management responsibility lies with the state apparatus. It is particularly true for climate disruption, where markets have failed to heed the high-end risks where the range of potential second-order impacts is difficult to articulate, and risks and impacts have been exacerbated by three decades of inaction.

Neo-classical economics assumes an idealised world of market participants operating with "perfect knowledge" to produce efficient prices and optimal outcomes. If risk is quantifiable, then it can be priced, so that uncertainty is tamed by the market. But markets so far have been poor at recognising and pricing risks and suffer from the "tragedy of the horizon"[97] and the "tragedy of the commons" hence greenhouse gas emissions continue to rise at worst-case rates.

89 Chenet, H et al. 2021, op cit..

90 ECB, 2020, Financial stability review, European Central Bank, Frankfurt Am Main, ecb.europa.eu/pub/pdf/fsr/ecb.fsr202011~b7be9ae1f1.en.pdf.

91 Glendon, S 2019, 'A price, but at what cost?', Woodwell Climate Research Centre, 18 February.

92 Ambrose, J 2021, 'Prepare for disorderly shift to low-carbon era, firms and investors told', The Guardian, 26 May

93 Kormann, C 2020, 'Will big business finally reckon with the climate crisis?', New Yorker, 4 February.

94 Wallace-Wells, D 2021, Twitter, twitter.com/dwallacewells/status/1389580150333972490.

95 Steffen, A 2021, 'The last hurrah', The snap forward, 27 April.

96 Wallace-Wells, D 2021, Twitter, twitter.com/dwallacewells/status/1389580594762469378.

97 Carney, M 2015, 'Breaking the tragedy of the horizon - climate change and financial stability', Bank of England, 29 September.

As noted above, Kay and King explain that we live in a world of radical uncertainty in which our understanding of the present is imperfect and our understanding of the future even more limited. When our world ends, they say, it will likely be "as a result of some contingency we have failed even to imagine", so "good strategies for a radically uncertain world avoid the pretence of knowledge — the models and bogus quantifications which require users to make up things they do not know and could not know".[98]

CRFRs are uncertain in their severity and time frames, and are not well suited to conventional risk-management tools. UK researchers say that:

> Climate-related financial risks (CRFR) — both physical and transition risks — are subject to radical uncertainty and are not well suited to conventional ergodic and exogenous financial risk analysis, which makes the quest for accurate 'measurement' particularly difficult. Radical uncertainty prevents the generation of reliable ('efficient') prices and as such prevents financial system participants from having the deterministic or probabilistic vision of the future that they are looking for... Thus, the existing approach to CRFR is not fit for purpose. Scenarios and stress testing are useful tools in the face of uncertainty, but the quantitative modelling they rely upon cannot compensate for the 'unknown unknowns' attached to underlying socio-economic phenomena and mechanisms (emphasis added).[99]

They say that concomitant reactions amongst market players would likely lead to a network of adverse cascade effects, constituting a systemic risk to the financial system as a whole.

As well, the financial impacts of specific future climate events at the level of an institution or asset are also uncertain. Under a specific degree of warming with resulting long-run consequences, such as sea levels, "the exact effect on, and potential damage to, for example, a specific building or infrastructure, is highly uncertain, as are the associated cost, adaptation and anticipation of such impacts, as well as second round effects".[100]

Climate change is not a market optimisation problem, it's a risk problem — the risk of the loss of capitalism — says Spencer Glendon.[101] He also notes that the economics of climate change "will be seen as one of the worst mistakes humans have made, much worse than any of the denialists".[102]

The problem is exacerbated by the failure so far to decouple resource use from consumption, as well as carbon pollution from production.[103] Business has consistently blocked the required state-level intervention and leadership. Inflamed by the fuel of financialisation which triggered the GFC, the lack of action on planetary limits, including resource depletion and climate disruption, will further destabilise financial markets and global security. At this point the state — capable of delivering fast, disruptive change — will be forced to respond to systemic exceedance of planetary limits and market failure, take emergency action, redirect current economic behaviour to socially useful ends and scale back production as necessary.

Analytical capacity

And finally, there is the question of the capacity of regulators and public and private institutions to analyse the risks. A 2020 ECB initiative found that: "Despite the fact that the majority of institutions have implemented one or more sustainability policies, most of the institutions do not have the tools to assess the impact of climate-related and environmental risks on their balance sheet."[104]

As well, researchers say:

- The vast majority of financial risk management approaches "are purely quantitative and rely on sophisticated statistical and stochastic modelling tools", but CRFR are not well suited to conventional risk management tools and indicators due to the high level of uncertainty around both severity and time frames; and
- Scenario analysis and in particular stress testing in finance "usually rely on a comparison of a limited set of scenarios (typically one business-as-usual versus an adverse one) over short time periods (generally one to three years), with the reaction function of the agents based upon historical data". But even with realistic scenarios it is difficult, if not impossible, to deal with unprecedented events on the basis of historical events.[105]

98 Kay, J & King, M 2020, op. cit
99 Chenet, H et al. 2021, op. cit.
100 Chenet, H, et al. 2021, op. cit.
101 Glendon, S 2020, 'Climate risk and the capital markets', Fintech TV, fintech.tv/climate-risk-and-the-capital-markets.
102 Kormann, C 2020, 'op. cit.
103 Vadén, T et al. 2020, 'Decoupling for ecological sustainability: A categorisation and review of research literature', Environmental Science & Policy, vol. 112, pp. 236-244
104 ECB, 2020, Guide on climate-related and environmental risks - Supervisory expectations relating to risk management and disclosure, European Central Bank, Frankfurt Am Main.
105 Chenet, H, et al. 2021, op. cit.

DROWNING MORTGAGES: BIG TROUBLE QUICKLY

Market sentiment can change quickly. And there is no greater vulnerability for the financial system than its exposure to the real estate sector, with domestic property, private assets and public infrastructure subject to inundation from rising sea levels. The problem is that the future rate of sea-level rise has been underestimated by most policy-makers, and by markets.

The "official" view of sea-level rise from the IPCC is a number below one metre by 2100, with some caveats. Many scientists think it will be over a metre; some say it is difficult to establish an upper bound. Former NASA climate chief James Hansen once famously said that he would "bet $1000 to a doughnut" that his estimate of a 5-metre rise by 2100 would be closer to the eventuality than the IPCC estimate.[106] The US military uses a 2-metre sea-level rise scenario, and US government agencies have a high scenario of 2.5 metres.

A report from the McKinsey Global Institute, leveraging climate hazard data from the Woodwell Climate Research Center, shows how societies and economies could cross critical thresholds and face new vulnerabilities over less time than the duration of a typical mortgage.[107] Speaking at the 2019 Sohn Investment Conference, Spencer Glendon, now at Woodwell, explained how inundation will overturn expectations about Florida's future, and destabilise bond markets:

> "The problem is that Florida's economy is built on 30-year debt. Lots of people are putting long-term money to work in Florida. And that long-term debt is underwritten by annual insurance. The condition of having a mortgage is that you have insurance, but the problem is that while the mortgage people offer you 30 years, the insurance people only offer you one. And they have made no commitment to do that further out.
>
> "We are doing work that shows there will be no insurance in lots of Florida quite soon. You shouldn't be lending now, and as Florida gets wetter and saltier and hotter and more volatile, insurance markets will dry up. It's already foolish to lend money for 30 years for municipal bonds and for mortgages. So when will Florida's economy fall apart?
>
> "People talk about when it will be under water. No, no, it's not when it's under water, it's when people stop lending 30-year money. And when that happens, everything will go with it.
>
> "I spend my time now thinking about the weaknesses in society, the vulnerabilities that come from the assumptions we have made about climate. Everyone assumes that the population graph in Florida will keep rising … and they all assume that it will stay super nice. And they don't charge income tax. They are utterly dependent on real estate. When real estate even slows in Florida, the economy will go to hell.
>
> "When will this happen? It could happen tomorrow. As soon as people stop lending for 30 years, as soon as Moodys starts asking about municipal bond financing, it could be in big trouble quickly.
>
> "Civilization is built on a stable climate and we are now moving rapidly into instability. And I'm quite sure that people's financial models don't reflect that."[108]

106 Hansen, J 2007, 'Huge sea level rises are coming – unless we act now', New Scientist, July 25.

107 WCRC 2020, 'McKinsey report: Climate risk an important part of corporate, government decision-making', Woodwell Climate Research Centre, 17 January.

108 Glendon, S 2019, 'Spencer Glendon at the 2019 Sohn Investment Conference', YouTube, 21 May.

NGFS FINANCIAL RISK SCENARIOS AND "NET ZERO 2050"

What does "Net zero 2050" (NZ2050) really mean? It is a critical question.

A number of institutions, including the IPCC, the IEA and the NGFS have produced NZ2050 scenarios, which will substantially influence national climate policy commitments made in the lead up to the COP26 climate summit in Glasgow in November 2021. Those scenarios and the models and assumptions underlying them will frame the outcome, as happened in 2015. The *Paris Agreement* was lauded for its 1.5°C target, but had an underlying framework of target overshoot and a large role for currently non-viable technologies such as bioenergy with carbon capture and storage (BECCS), backed by a good dose of scientific reticence about the state of the climate system and its tipping points.

The revised NGFS scenarios, published in June 2021, are being pitched as a standard for policymakers. The NGFS says the scenarios are "a foundation for analysis across many institutions, creating much needed consistency and comparability of results. A growing number of central banks, supervisors and private firms are already using NGFS scenarios... [It is] a suite of models, supported by a consortium of world leading climate scientists and modelling groups [and a] consistent set of pathways for global changes in policy, the energy system, and the climate."[109] In other words, NGFS is leading the way.

Australian financial regulators, including APRA, draw on the NGFS scenarios, so their efficacy is materially relevant to the performance of those regulators.

The NGFS provides six scenarios, four of which result in less than 2°C of warming by 2100, plus one at over 2°C and another at more than 3°C. The optimum scenario, called "Net zero 2050", is clearly privileged in the NGFS presentations as the most desirable, and is given the most attention.

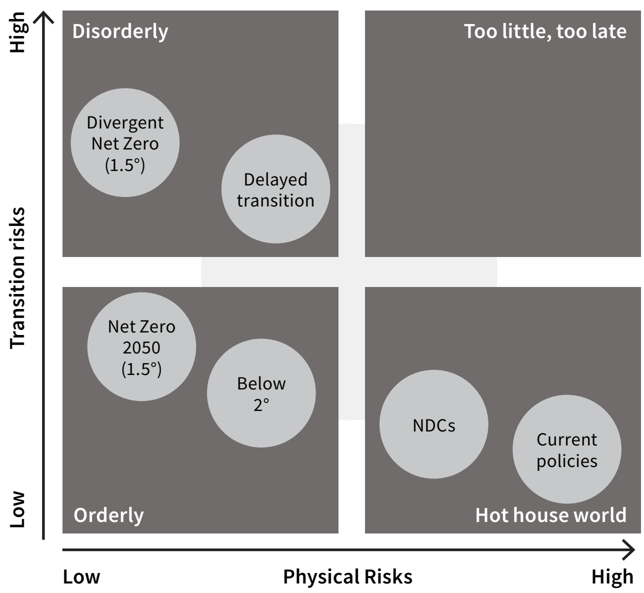
Like the Paris framing and the 2018 IPCC special report on 1.5°C, the NGFS scenarios rely on IAMs. Such models reflect modellers' view of society. Depending on how modellers perceive the roots of the problem to be solved, they will "design the model structure, including possible instruments and relationships within the model accordingly… Hence, the very structure of a model depends on the modeller's beliefs about the functioning of society."[110] Consequently, IAM results have the capacity to privilege particular pathways and entice policymakers into thinking that the forecasts the models generate have some kind of scientific legitimacy. And this is the fundamental problem with the NGFS scenarios.

It is clear from NGFS presentation that the focus is on scenario choice, not risk management. Recognising that risks may be existential, especially in the higher scenarios, would bring a completely different approach to thinking about the risks, but this is entirely missing. And IAMs — like IPCC reports — focus on the probabilities, not the bad possibilities.

Some key issues of concern include the following.

Scenario choice: The NGFS identifies four scenario quadrants: "Orderly", "Disorderly", "Hot house world", and "Too little, too late". Four under-2°C scenarios fit into the first two quadrants, and two are in "Hot house world". But there are no scenarios for the "Too little, too late" quadrant, even though it is important in scenario work to focus on the bad possibilities. As well, the two scenarios above 2°C appear poorly developed, whereas sensible risk management says they deserve special attention. The quantification of damages in the NGFS climate scenarios is grossly underdone. In the 3°+C scenario "Current policies" the effect on GDP at 2100 is −13%, which is extraordinarily low and stretches credibility. If there was a reasonable grasp of the consequences of more than 3°C of warming, then this scenario would be in the "Too little, too late" quadrant, because not only will the damage be very high, but so will the cost to business trying to transition to and survive in that world of catastrophe and chaos.

NGFS scenarios Framework



109 NGFS 2021, op. cit.

110 Ellenbeck, S & Lilliestam, J 2019, 'How modelers construct energy costs: Discursive elements in energy system and Integrated Assessment Models', Energy Research & Social Science, vol. 47, pp. 69-77.

Underestimating damages: IAMs assume damages can be quantified, when in reality they are radically uncertain, and perhaps infinite, especially in the higher-warming scenarios. As noted earlier, some climate system tipping points have already been passed, and cascade effects are dangerously close. The NGFS scenarios chronically underestimate future damage, using IAMs that basically ignore non-linearities and cascades. The NGFS admits its damage estimates from physical risks "only cover a limited number of risk transmission channels. For example, they do not capture the risks from sea-level rise or severe weather. They also assume socio-economic factors such as population, migration and conflict remain constant even at high levels of warming."[111] This, in itself, is enough to disqualify these scenarios from being seen as credible stories about alternative futures.

Technology choices and technocratic dreaming: Modellers make choices about the future mix of energy technologies. The recent IEA NZ2050 scenario, for example, has a doubling of nuclear power by 2050.[112] Likewise, the NGFS scenarios allocate a sizeable role for fossil fuels in 30 years time. In 2050, in the NZ2050 scenario, gas production is still 50% of the 2020 level; fossil fuels are 32% of primary energy in the NZ2050 scenario and 50% in the "Below 2°C scenario". To deal with this, a number of technologies either not proven or not deployed at scale are assumed, including direct air capture of CO_2, and large-scale use of carbon capture and storage (CCS). Of the CO_2 emissions savings to 2050, almost half come from technologies under development rather than those already in the market. Whilst the scenarios rely on a good deal on carbon dioxide removal (CDR), it is acknowledged that CDR is a big "if", because such technologies "only currently take place on a limited scale and face their own challenges".[113]

Sustainability: The scenarios assume that the world economy will continue to grow for another 30 years as it has in recent decades, such that global production doubles between 2020 and 2050. Given that most resource use has not been significantly decoupled from production, this implies that the human world will become even more destructive of the planet and its finite resources. If at present humans consume 1.7 planet's worth of resources each year, how much more irreparable damage will be done by 2050, and how many more of Earth's planetary boundaries will be exceeded? No scenarios focus on lower-growth alternatives.

Fuels versus food: The purpose of CDR should be to reduce the level of atmospheric CO_2 back to a safe level. But if you continue to use a lot of fossil fuels, then CDR has to be diverted into being an "offset" for continuing emissions, and hence demand grows for "natural offsets" such as forestation and the land and water required. Another demand on land is BECCS: biofuels supply 20% of primary energy by 2050 in the NZ2050 scenario. Carbon sequestration in the NZ2050 scenario is almost 8 billion tonnes of CO_2 by 2050, including more than 3 billion tonnes from BECCS, even though current drawdown from BECCS is practically zero. BECCS uses crops grown for energy, and competes with land for food. This means that in the NZ2050 scenario, the amount of land available for crops *decreases* by 8% by 2050, even as GDP doubles and population grows by 20% in 30 years. Global demand for food would likely be around 50% higher than at present, with less cropland than now, which makes the land-use assumptions, in *Yes Minister* terms, "courageous".

More broadly, there are the questions of the efficacy of scenarios and the role of climate–economy models. As discussed above, "Scenario planning does not forecast, predict or express preferences for the future; rather the story-telling paints internally-consistent pictures of alternative worlds which might emerge given certain assumptions, that are credible in the light of both known and lesser known factors." But some NGFS scenario assumptions are either not credible or ignore significant factors.

The NGFS puts its model-based scenarios at the centre of the task that central banks and regulators face with climate-driven financial disruption. It claims that these "detailed scenarios" are a "milestone" in overcoming "a major obstacle" and a "foundation for analysis" of the risks. But the reality is that they are not adequately addressing the real risks and uncertainties of climate change.

BIS's *The green swan* report concludes that scenario-based analysis "is only a partial solution to apprehend the risks posed by climate change for financial stability", in part because the models being used "may not be able to accurately predict the economic and financial impact of climate change because of the complexity of the links and the intrinsic non-linearity of the related phenomena".[114]

Moreover, the scenarios presented by NGFS do not take into account and describe the full range of alternatives. The four key scenarios are based on one set of assumptions: Paris compliant, continued and unsustainable economic growth, a reliance on technologies not yet proven or deployed at scale, overshoot of the temperature target, a big role for gas for many decades to come, and denial of key dynamics of the climate system. No time frame shorter than 2050 is explored, nor any scenarios with active cooling in the shorter term to restore vulnerable ecosystems. This suggests the NGFS exercise has been largely about mapping a predetermined path.

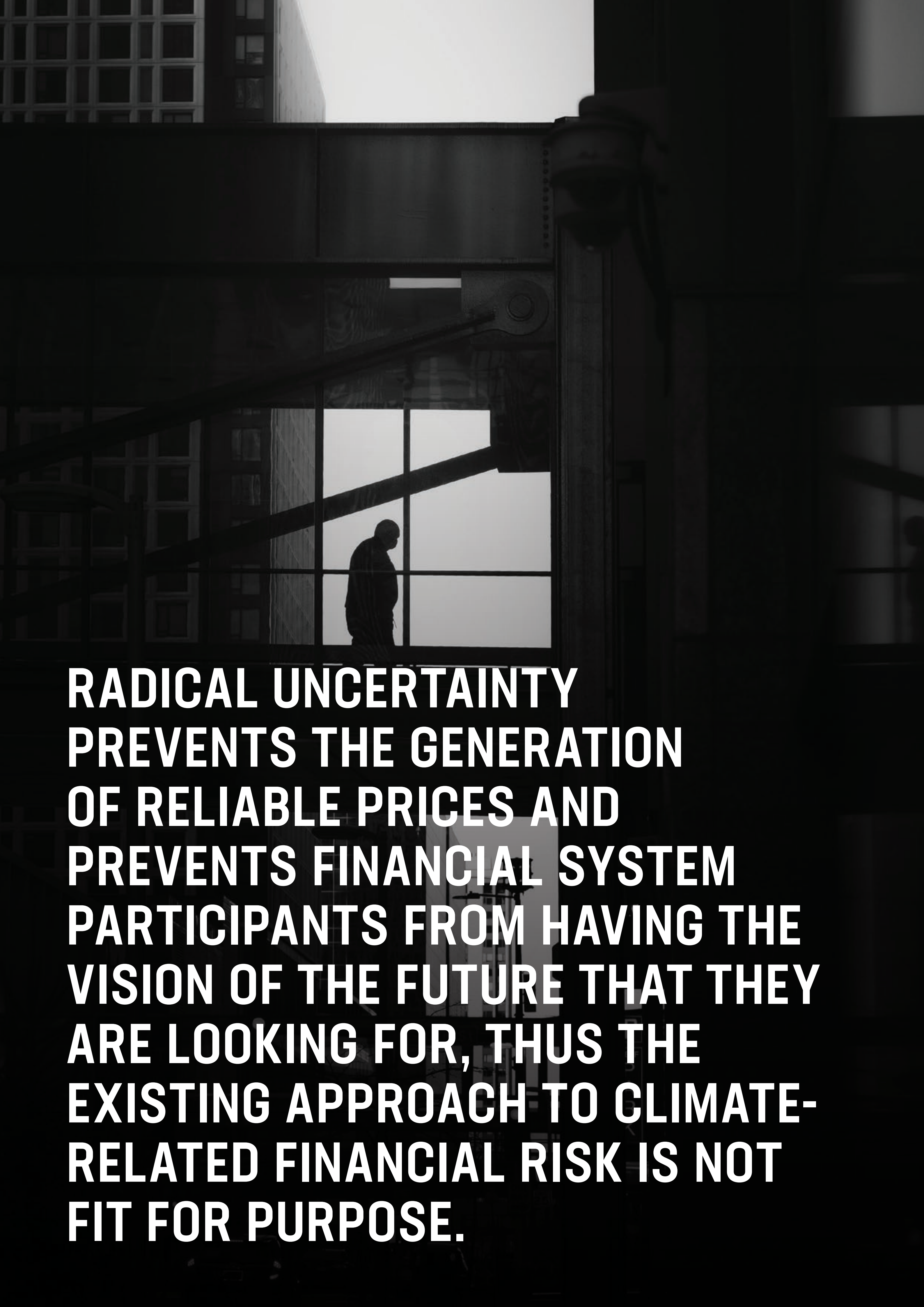
In a word, the scenarios privilege advocacy of one particular path over a dispassionate articulation of multiple, wide-ranging perspectives and possible, alternative futures. Indeed, it is arguable, given the evidence of climate impacts given in this report, that most of the NGFS scenarios should reside in the "Too little, too late" quadrant.

111 NGFS 2021, op. cit.

112 IEA 2021, Net zero by 2050: A roadmap for the global energy sector, International Energy Agency.

113 NGFS 2021, op. cit.

114 Bolton, P et al. 2020, op. cit.



RADICAL UNCERTAINTY PREVENTS THE GENERATION OF RELIABLE PRICES AND PREVENTS FINANCIAL SYSTEM PARTICIPANTS FROM HAVING THE VISION OF THE FUTURE THAT THEY ARE LOOKING FOR, THUS THE EXISTING APPROACH TO CLIMATE-RELATED FINANCIAL RISK IS NOT FIT FOR PURPOSE.

A PRECAUTIONARY APPROACH

> "Risk-management approaches may be particularly challenged when it comes to measuring risks that will impact all agents and interact with multiple other dynamic patterns … Even if climate-related financial risks could be measured, it is not clear that it would be possible to manage them."[115]

This report posed the question: "Can the banking system survive climate warming in excess of 3˚C?" The answer is that the risks and uncertainty are such that this is unlikely.

It is very likely that the description of 3˚C warming impacts as "catastrophic" is close to the mark. The consequences for human society of the vast physical changes that this warming will wreak on the world are radically uncertain, probably somewhere between chaotic and existential. In those circumstances, the nature of economies can be speculated upon, but scenarios cannot be constructed that would have even a reasonable chance of characterising the financial system.

Gaining knowledge about the world at 3˚C leads to one conclusion: it must be avoided at all cost, and that demands a precautionary approach to risk management. Special precautions that go well beyond conventional risk-management practice are required if the increased likelihood of very large climate impacts, potentially existential, are to be adequately dealt with. Hopefully this was discussed in June 2021 when bankers gathered for an unprecedented BIS Green Swan Conference[116] to talk about the fear that climate change poses under-appreciated economic risks.[117]

A prudent, precautionary risk-management approach means a tough and objective look at the real risks to which we are exposed. The fat-tail risks may be damaging beyond quantification and the potential consequences would be devastating for human society. It is important to understand the potential of, and plan for, the worst that can happen, and be pleasantly surprised if it doesn't.

Focusing on middle-of-the-range economic outcomes may result in unexpected catastrophic events that we should have seen coming. Existential risks are not amenable to the reactive (learn from failure) approach of conventional risk management, and we cannot necessarily rely on the institutions, moral norms, or social attitudes developed from our experience with managing other sorts of risks.

The following guidelines are appropriate for assessing such climate risks:[118]

1. Use the best available information in an open, transparent and inclusive manner, drawing from diverse sources and methods of analysis, whether this is proven science, or expert judgment. A best estimate is usually better than no estimate at all.
2. Take a normative approach to managing risks, setting targets and developing strategy, assessing risks in relation to objectives, or interests. Start from an understanding of what it is that we wish to avoid; then assess its likelihood. Be explicit about value judgments, recognising that they are essentially subjective.
3. Recognise that the science of climate change is inherently complex because it describes the dynamics of a multi-dimensional, non-linear system, involving many subsystems and networks of adverse cascade effects; and recognise that climate–economy models are of limited use.
4. Identify the worst, as well as most likely, cases. Properly assess the full range of possibilities, recognising that a very low probability may correspond to a very high risk, if the impact is catastrophic.
5. Apply the precautionary principle when faced with uncertain threats that may cause systemic ruin, implementing measures to ensure those threats do not materialise, to the extent that is possible.
6. Take a holistic view and integrate responses — whether that be across government departments, or across national and regional boundaries — recognising that complexity cannot be treated in separate "silos".

Researchers advocate a precautionary financial policy approach to CRFR, recognising that the principal challenges around regulators' supervisory roles are mandated time horizons that are too short to capture the significant materiality of CRFR today, and the strong economic and distributional policy consequences of such actions are beyond their mandates. They say the "wait until we have better understanding" approach is poor policy given the potentially catastrophic and irreversible effects of delay, and under present regulatory policies "it is impossible to guarantee that action will not be postponed until it is too late".[119]

115 Oman, W & Svartzman, R 2021, What justifies sustainable finance measures? Financial-economic interactions and possible implications for policymakers', CESifo Forum, vol. 22, pp. 3-11.

116 BIS 2021, 'The Green Swan Conference - Coordinating finance on climate', Bank for International Settlements. bis.org/events/green_swan_2021/overview.htm

117 Tett, G et al. 2021, 'Central bank action on climate is "imperative", says Banque de France', Financial Times, 3 June.

118 Drawing on King, D, et al. 2016, op. cit.

119 Chenet, H et al, 2021, op. cit.

CONCLUSION

From the analysis above, it is clear that the fashionable reliance on scenarios, built around theoretical emission reductions and average global temperature increases, carries with it the danger of obscuring the real impact of climate change and creating complacency amongst global leaders.

Simply accumulating knowledge and making it transparent is not enough. Writing in Bloomberg, Australian analyst Kate Mackenzie says that the insistence on more data and analysis is at odds with the dangers we face:

> The implications of heat-trapping gases accruing in the atmosphere don't allow for half-measures, even within strictly defined parameters of safeguarding financial stability. How do you measure the impact of a marginal ton of carbon dioxide released when some scientists believe we're already close to dangerous tipping points? Politicians who say combating climate change isn't a job for central banks are wrong. A core responsibility for most of them is to maintain price and financial stability, which is directly threatened by global warming … if central banks limit themselves to modeling scenarios and developing stress tests, while waiting for potentially stronger policy action from others, climate-related threats to financial stability will only grow.[120]

The BIS 2020 report concluded that central banks can have a role to play "in helping coordinate the measures to fight climate change. Those include climate mitigation policies such as carbon pricing, the integration of sustainability into financial practices and accounting frameworks, the search for appropriate policy mixes, and the development of new financial mechanisms at the international level."[121]

The precautionary principle is suited to "ruin" problems, because in such cases "what appear to be small and reasonable risks accumulate inevitably to certain irreversible harm".[122]

One of the problems leading up to the GFC was regulators' focus on individual institutions, rather than systemic risks to the financial system that were created endogenously. What was prudent behaviour for a firm was highly imprudent from a macro perspective. Thus:

> Macroprudential policy focuses on the stability of the system as a whole by mitigating the systemic financial risks to the macroeconomy through pre-emptive interventions. As such, macroprudential policy can be seen as taking a precautionary approach… there is a strong case for macroprudential policy to be extended to ensure the financial system is also more resilient to hard to predict climate-change related financial shocks… our central argument is that both the systemic magnitude and irreversibility of the threats associated with CRFR, and the radical uncertainty attached to them, justify the development of an explicit climate-related Precautionary Financial Policy (PFP). This would incorporate all aspects of financial policy, including macroprudential and monetary policy interventions.[123]

This is the challenge for all financial system regulators. Better information tells the driver that the bus is closer to the cliff than thought. But that information has been accumulating, and ignored, for three decades, to the point that an explicit climate-related precautionary financial policy is now urgently required if the financial system is to avoid plunging over the edge.

This must be taken up in the context of the NGFS scenarios, their application in Australia and elsewhere. It also applies to climate change policy in the broadest sense where IEA and IPCC scenarios are used in charting pathways to achieve, for example, *Paris Agreement* outcomes, which in themselves are inadequate to address the climate threat we face.

Regulators need to move beyond scenario analysis and transparent disclosure of climate impact, to work with scientists, policy-makers, business and financial leaders in defining the precautionary action that must now be taken to prevent catastrophic climate impacts becoming locked-in. If the financial system is to survive and prosper, such precautionary action must ensure temperature outcomes do not trigger further tipping points or a Hothouse Earth cascade, and return the system to the stable climate conditions under which human civilisation flourished. This means emergency action to keep temperature increase to a minimum, coupled with drawdown of current atmospheric carbon concentrations.

The NGFS and TCFD recommendations, along with regulatory guidance in general, exert great influence over financial and corporate market responses to climate risk. We urge that these recommendations and guidance be reframed to encompass emergency precautionary action appropriate to the threats outlined in this paper.

120 Mackenzie, K 2021, 'Central banks finally grasp the need for daring climate action', Bloomberg Green, 4 June.

121 Bolton, P et al. 2020, op. cit.

122 Chenet, H et al, 2021, op. cit.

123 Chenet, H et al, 2021, op. cit..

GLOSSARY

ASIC	Australian Securities and Investments Commission
APRA	Australian Prudential Regulatory Authority
BECCS	Bioenergy with carbon capture and storage
BIS	Bank for International Settlements
BoE	Bank of England
CBA	cost–benefit analysis
CO_2	carbon dioxide
COP26	26th meeting in Glasgow of the Conference of the Parties to the UNFCCC
CRFR	climate-related financial risks
CFR	Council for Financial Regulators
ECB	European Central Bank
existential	an adverse outcome that will either annihilate intelligent life or permanently and drastically curtail its potential
feedback	self-reinforcing process
FSB	Financial Stability Board
GCF	Global Challenges Foundation
GFC	Global Financial Crisis
Hothouse Earth	A scenario in which non-linear system feedbacks and their mutual interaction cascade to drive Earth's climate to a "point of no return"
IAMs	Integrated Assessment Models
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
NGFS	Network for Greening the Financial System
NZ2050	Net zero 2050
probabilistic	based on theory of probability, outcomes with knowable probabilities
RBA	Reserve Bank of Australia
TCFD	Taskforce on Climate-related Financial Disclosures
tipping point	a threshold, or moment of critical mass, for system-level change
UNFCCC	United Nations Framework Convention on Climate Change
WAIS	West Antarctic Ice Sheet

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